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THE MILKY WAY IN CEPHEUS

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ABSTRACT

This investigation in Cepheus provides data on the surface distribution of the stars to the fifteenth magnitude over an area of approximately 750 square degrees.

Available information concerning the absorbing and scattering power of the dark material in this direction shows that no part of the field may be considered unobscured. The brightest regions, those just south of the galactic plane, seem to be affected by not more than 1^m0 absorption in 2000 parsecs. Farther south, in divisions designated as "zones," because of their apparent uniformity, there is considerable basis for the assumption of an irregular layer of absorbing material roughly oriented to the galactic plane. The most effective width of this layer is between galactic latitudes $+10°$ and $-10°$, where the total absorption probably does not exceed 1^m0 per kiloparsec. In three parts of the Cepheus field, the Northern Coalsack, a region centered at $l = 80°$, $b = +16°$, and just east of the North America nebula, the absorption reaches at least 3^m0 in 2000 parsecs.

The total absorption affecting each of the various divisions in Cepheus was estimated, and solutions for the densities were made. In most cases a constant coefficient of absorption, starting in the neighborhood of the sun and extending to the distance at which the absorbing layer ceases to be effective, was as satisfactory an assumption as could be made with the present data. The densities north of the galactic plane were found to be approximately constant for several hundred parsecs, after which they dropped sharply. Just south of the plane a persistent rise in the densities was found within 500 parsecs of the sun, but for distances greater than 800 parsecs the density functions were similar to those derived for the northern divisions. An investigation of the available spectral material pointed to a definite deviation from a "normal" stellar distribution in Cepheus throughout the area south of the galactic equator. The reality of these density increases must depend on additional data.

From this preliminary survey in Cepheus several comparatively clear regions have been found where color indices of stars of known spectral class would provide a much more reliable solution of the density function. Further investigation has been started on one of these areas.

The main purpose of this preliminary investigation in Cepheus was to provide data on the surface distribution of the stars to the fifteenth magnitude over an area of approximately 750 square degrees. With these data it has been possible to show for the first time the interrelation of the various parts of the field, particularly those studied previously by other investigators. A more important result, however, has been the discovery of several regions near the galactic equator, where the effect of the absorbing material seems comparatively small. It is at these places that more detailed investigation seems desirable and where the study of the field is being continued at the present time.

The region considered in this paper covers about three-fourths of the area between 20^h30^m and 0^h in right ascension and from $+45°$ to $+75°$ in declination. In galactic co-

ordinates, referred to the Harvard pole at $\alpha = 12^h40^m$, $\delta = +28°$, the boundaries in galactic longitude are 50° and 90°, while those of galactic latitude are $+20°$ and $-20°$.

The Cepheus study is one of a number of "Investigations of Galactic Structure,"[1] which are being carried out on a co-operative basis by the institutions working together as the informal "Star-counting Circuit," which includes Harvard, Armagh, Denison University, Case School, the University of Illinois, Randolph-Macon Woman's College, and Tonanzintla.

THE BASIS OF THE COUNTS

The plates used for the Cepheus investigation were taken with the 4-inch Ross-Lundin camera at the Oak Ridge Station of Harvard College Observatory. Later four plates taken with the 4-inch Ross-Fecker camera at the University of Illinois were loaned by Dr. R. H. Baker so that certain critical areas could be checked. The instruments are both 28 inches in focal length, and the scale of the plates is 290″ per millimeter. The twenty centers on which the plates were taken were spaced about 5° apart, so that the minimum overlap on any plate was one-third of the counted area. Stars between magnitudes 9.0 and 13.0 were counted on plates exposed for 30 minutes with half-aperture, while the fainter counts to magnitude 15.0 were made on plates which had a 60-minute exposure with full aperture. The average counting limit was the fifteenth magnitude, but several plates in the northern part of the field failed by nearly a magnitude to reach this limit, and no attempt was made to extrapolate the counts made on these plates.

The technique of counting was similar to that used in previous contributions to the series of "Investigations of Galactic Structure." The approximately circular area, in which all the counts were made and the transfer of sequences was done, included approximately 50 square degrees. The reference scale, the same one used by Dr. R. H. Baker[2] in his study of Cassiopeia, served for both calibrations and counting.

The standards used for calibrating the scale were drawn from two sources. The magnitudes of stars brighter than $13^m.0$ were taken from the *Bergedorfer Spektral-Durchmusterung*, and for fainter stars the magnitudes in the *Mount Wilson Catalogue of Selected Areas 1–139*[3] were used.

The Selected Areas were usually located near the center of the countable area, so that in making the transfer to an adjacent plate the group of stars often fell where the quality of image was poor. To avoid a correction dependent on the distance of the sequence from the center of the plate, the following method was used: A secondary sequence was chosen on a Selected Area plate in such a position that it would be diametrically located with respect to the center of the adjacent plate. In this way the effect of the position was always counterbalanced, and all sequences were transferred well within the area of acceptable images. To insure homogeneity over the entire region, calibrations were made, if possible, from two directions. A comparison of the curves derived from the two sets of measurements rarely indicated a difference of more than 0.1 mag. This was considered a satisfactory standard for the reliability of the dependent sequences.

THE RELIABILITY OF THE COUNTS

In order to determine to what extent the Cepheus star counts were subject to systematic and accidental errors, various comparisons of the observed values of $\log N(m)$, i.e., the number of stars per square degree of apparent magnitude m or brighter, have been made. It should be noticed that no correction of the original data seemed desirable except in the one case, where the error exceeded $0^m.15$.

The overlapping of the plates provided a way of investigating errors in counting which

[1] Bart J. Bok, *The Distribution of the Stars in Space*, p. 58, Chicago: University of Chicago Press, 1937.

[2] *Harvard Circ.*, No. 424, 1939.

[3] *Carnegie Institution of Washington Pub.*, No. 402, 1930.

would result from the position of the image in the countable area. From four pairs of plates on which the edge of one coincided with the central portion of the adjoining plate, differences of log $N(m)$ measured in the direction "center of the plate minus edge of the plate" were found. It is evident from the results of Table 1 that a systematic trend exists in the sense that more stars seem to have been counted at the edge of the plate than in the center. Since the mean difference in magnitudes is only -0^m06, no correction has been made.

The actual counting which forms the basis of this discussion was done during a consecutive period of several months. Frequent checks were made over this interval to detect changes of procedure which would affect the counts systematically, but there was no reason to believe that such changes occurred.

A measure of the internal consistency of the magnitude system over the whole field was available from the comparison of differences in log $N(m)$ on overlapping plates for identical regions. In each of the comparisons four plates, one pair of long exposures and one pair of short exposures, were used. The five regions investigated were scattered over

TABLE 1

SYSTEMATIC ERRORS IN LOG $N(m)$ FROM POSITION ON PLATE

(Center *minus* Edge)

PAIRS OF PLATES	m						
	9.0	10.0	11.0	12.0	13.0	14.0	15.0
I	0.00	0.00	+0.03	+0.01	+0.04	+0.07	+0.08
II	+ .07	+ .05	− .02	− .04	+ .02	− .10	− .10
III	− .05	.00	− .10	− .07	− .05	− .07	− .02
IV	−0.05	−0.10	−0.07	−0.06	−0.04	−0.02	−0.01
Mean in log $N(m)$	−0.01	−0.01	−0.04	−0.04	−0.01	−0.03	−0.01
Mean in magnitude	−0.03	−0.03	−0.12	−0.12	−0.03	−0.09	−0.03

the entire Cepheus area, so that no single plate entered more than once into the comparison. In Table 2 these differences between the corresponding values of log $N(m)$ derived from overlapping plates of the same region are tabulated, together with the probable errors of a single determination of log $N(m)$.

A final test of the accuracy of the counts was made by comparing them with those based on the *Durchmusterung* data for the Selected Areas.

For the stars brighter than 13^m0 the values of log $N(m)$, derived by van Rhijn and included in the *Bergedorfer Spektral-Durchmusterung*, apply to a region of approximately $12\frac{1}{4}$ square degrees centered on the given Selected Area.

Data for the fainter stars are also taken from van Rhijn's counts, which were made in the *Mount Wilson Catalogue of Selected Areas* and given in *Groningen Publication* No. 43. These areas cover only about 0.12 square degree. To obtain a more comparable area of 0.44 square degree, values of log $N(m)$ found in *Harvard Annals*, Volume **101,** corrected to the system of the *Mount Wilson Catalogue*, have been included in the comparison.

In the case of the faint stars it seemed that the values of log $N(m)$ computed from less than 9 *rêseau* squares, which is about 1.4 square degrees on the Cepheus plates, could be considered scarcely representative. The fact remains, however, that such a region is nearly twelve times larger than that counted in the *Mount Wilson Catalogue;* and even in comparison with *Harvard Annals*, Volume **101,** it differs by the factor 3.

The results of the comparison are given in Table 3, where in the designated Selected Areas the differences between the values of log $N(m)$ for the *Durchmusterung* counts and those found in this investigation have been tabulated.

The Cepheus counts show satisfactory agreement with the *Durchmusterung* counts with the exception of the faintest limit. Here too few stars have been counted. Accordingly, a correction of +0.04 in log $N(m)$ was made to all the counts at magnitude 15.0. This correction is the only change of the original counted numbers.

TABLE 2

VALUES OF Δ LOG $N(m)$ FROM OVERLAPPING PLATES

Comparison Regions	m						
	9.0	10.0	11.0	12.0	13.0	14.0	15.0
I	0.09	0.08	0.03	0.01	0.02	0.07	0.14
II	.02	.03	.04	.02	.02	.04	.01
III	.06	.04	.04	.04	.02	.05	.12
IV	.02	.06	.03	.07	.09	.04	.07
V	0.00	0.00	0.03	0.01	0.04	0.07	0.08
Mean	0.04	0.04	0.03	0.03	0.04	0.05	0.08
Probable error in log $N(m)$	±0.02	±0.02	±0.02	±0.02	±0.02	±0.03	±0.05
Probable error in magnitude	±0.06	±0.06	±0.06	±0.06	±0.06	±0.09	±0.15

TABLE 3

COMPARISON OF THE VALUE OF Δ LOG $N(m)$ FOR GIVEN SELECTED AREAS

(Risley *minus Durchmusterung*)

Magnitude	SA 2	SA 18	SA 41	SA 42	Mean	Comparison Source
9.0	+0.04	+0.01	−0.06	+0.02	+0.01	Bergedorf
10.0	+ .14	− .03	− .01	+ .06	+ .04	
11.0	+ .03	− .07	− .04	+ .08	.00	
12.0	+ .08	− .11	− .05	+ .04	− .01	
13.0	−0.06	−0.09	−0.04	+0.05	−0.04	
14.0	+0.10	−0.06	−0.04	+0.09	+0.02	Mount Wilson
15.0	.....	−0.10	−0.10	−0.10	−0.10	
14.0	0.00	−0.04	−0.05	+0.01	−0.02	Harvard
15.0	.....	−0.08	−0.14	−0.01	−0.08	

THE SURFACE DISTRIBUTION OF THE STARS

Before proceeding with the analysis of the counts the Cepheus field was mapped into 36 separate divisions, each of which appeared to be of approximately constant surface density. The various boundaries were drawn after the entire area had been carefully examined on the available plates and photographs, and this apparent distribution had been checked against the actual number of stars counted. Every effort was made to avoid a smoothing-out of the many existing small irregularities.

By means of Figure 1 the various parts of the Cepheus field may be identified. Several factors contributed to the somewhat random selection of the letters used. The designations of the eastern edge were taken to conform to adjoining and apparently similar regions in Cassiopeia, which had been investigated by Dr. R. H. Baker.[2] As the study proceeded, it was found that in certain regions the values of log $N(m)$ indicated a variation in surface distribution with galactic latitude, while in others there appeared to be small, though definite, gradations of brightness which were not sufficiently noticeable to be outlined by the counts on the individual plates. On the map of the field regions, C, E, and H show this subdivision by a number added to the original letter.

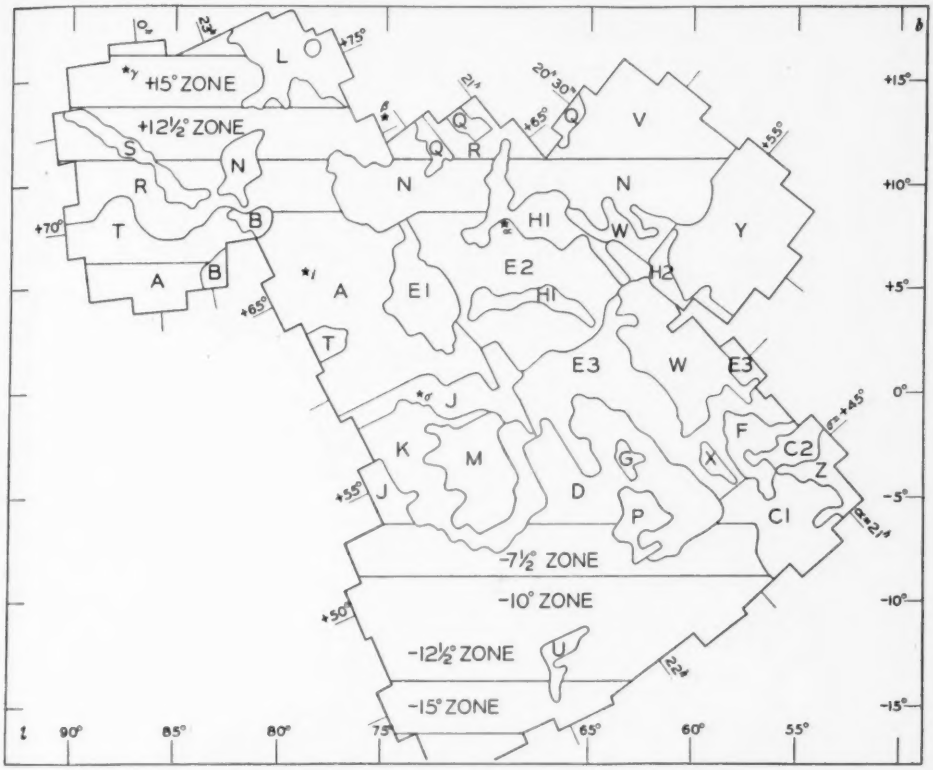

FIG. 1.—Divisions of the Cepheus field

After obvious small pieces of obscuration were removed, the apparently uniform regions in the northern and southern parts of the field were divided into zones 2.5° wide, thus minimizing any further difficulty with the "galactic concentration."

Table 4 summarizes the data derived from these divisions. Included are the co-ordinates of the center, the approximate area covered, the number of plates used in the determination of log $N(m)$, the values of log $N(m)$ over the interval from 9^m0 to 15^m0, and tentative values of the total obscuration at distances of 300 and 1000 parsecs.

Early in the investigation of the Cepheus field it was apparent that the divisions just south of the galactic equator are dimmed much less by obscuring material than those to the north. Regions M and K, sometimes referred to as the "Cepheus cloud," together with two smaller regions, F and G, at the same galactic latitude, were found to be comparatively free from absorption, the amount not exceeding 0^m5 in 1000 parsecs. Evidence for somewhat more absorption exists, however, in the southern zones, so designated

because of their apparent uniformity. The complexity of dark lanes and flares which is so characteristic of Cepheus north of the galactic plane even to latitude +17.5° leaves only two divisions, E1 and Y, where more detailed investigation by means of colors and spectra would appear to be feasible at the present time.

TABLE 4

MEAN LOG $N(m)$ FOR THE DIFFERENT DIVISIONS

Division	Position of the Center		Area (Square Degrees)	Number of Plates	Limiting Magnitude							Total Obscuration (Parsecs)	
	l	b			9.0	10.0	11.0	12.0	13.0	14.0	15.0	300	1000
Zone:													
+17.5°	.....	.....	5	2	0.50	0.80	1.20	1.58	1.86	2.08	.....	$0^m.5$	$1^m.8$
+15.0	.....	.....	20	4	0.41	0.86	1.26	1.64	1.95	2.20	.....	0.4	1.6
+12.5	.....	.....	30	6	0.53	0.88	1.22	1.59	1.88	2.13	.....	0.6	2.0
− 7.5	.....	.....	34	8	0.73	1.16	1.57	1.96	2.26	2.52	2.87	0.0	0.8
−10.0	.....	.....	40	10	0.67	1.11	1.51	1.88	2.19	2.46	2.82	0.3	1.0
−12.5	.....	.....	28	6	0.63	1.02	1.43	1.80	2.10	2.36	2.71	0.3	1.2
−15.0	.....	.....	25	4	0.58	0.97	1.39	1.74	2.04	2.30	2.63	0.3	1.3
−17.5	.....	.....	10	2	0.54	0.90	1.34	1.67	1.97	2.23	2.58	0.3	1.0
Region:													
A	80°	+ 4.0°	64	12	0.60	0.96	1.28	1.62	1.88	2.14	2.48	0.3	1.1
B	82	+ 7.0	8	4	0.20	0.66	1.08	1.42	1.62	1.88	.....	0.7	2.5
C 1	56	− 6.0	16	2	0.72	1.15	1.54	1.86	2.12	2.35	2.66	0.3	0.9
C 2	55	− 2.5	6	2	0.97	1.26	1.60	1.92	2.16	2.38	2.70	0.2	0.7
D	63	− 3.0	34	8	0.89	1.28	1.62	1.97	2.28	2.51	2.85	0.2	0.6
E 1	73	+ 5.0	15	4	0.92	1.19	1.50	1.84	2.13	2.38	2.70	0.3	0.9
E 2	68	+ 6.0	41	8	0.70	1.04	1.36	1.69	1.99	2.31	2.58	0.3	1.1
E 3	63	0.0	32	6	0.82	1.12	1.46	1.79	2.06	2.29	2.57	0.3	1.0
F	57	− 2.5	7	4	0.96	1.36	1.74	2.06	2.33	2.55	2.89	0.2	0.5
G	63	− 3.0	2	4	1.04	1.38	1.74	2.11	2.46	2.68	3.01	0.1	0.4
H 1	69	+ 9.0	23	4	0.36	0.80	1.14	1.48	1.77	2.10	2.36	0.6	1.9
H 2	61	+ 5.0	5	2	0.69	0.96	1.26	1.55	1.86	2.12	2.38	0.3	1.1
J	71	− 1.0	16	4	0.72	1.14	1.44	1.78	2.14	2.45	2.78	0.5	1.5
K	72	− 2.5	24	8	0.79	1.22	1.58	1.95	2.28	2.58	2.93	0.2	0.5
L	80	+16.0	13	2	0.07	0.56	0.96	1.30	1.55	1.76	.....	0.9	3.0
M	70	− 3.0	18	6	0.80	1.25	1.63	2.03	2.36	2.65	3.05	0.1	0.5
N	60–75	+10.0	68	10	0.63	1.02	1.38	1.73	2.03	2.32	2.56	0.3	1.1
P	62	− 6.0	7	4	0.49	0.93	1.39	1.76	2.07	2.38	2.66	0.3	1.0
Q	72	+12.5	7	4	0.60	0.90	1.19	1.49	1.76	2.04	2.30	0.7	2.2
R	75–90	+10.0	52	8	0.45	0.82	1.22	1.61	1.92	2.22	2.49	0.5	1.7
S	87	+11.0	8	4	0.40	0.74	1.06	1.38	1.68	1.96	.....	0.7	2.2
T	86	+ 7.5	19	6	0.40	0.84	1.18	1.52	1.76	1.98	2.25	0.6	2.0
U	66	−12.5	5	2	0.12	0.58	1.15	1.50	1.83	2.08	2.42	0.6	2.0
V	63	+13.5	26	2	0.65	1.00	1.40	1.72	2.06	2.30	2.52	0.0	1.2
W	61	+ 2.0	32	6	0.61	0.88	1.23	1.53	1.79	1.97	2.20	1.0	3.0
X	59	− 3.0	3	4	0.71	1.14	1.48	1.71	1.95	2.16	2.39	0.0	1.2
Y	57	+ 7.0	23	4	0.70	1.08	1.48	1.89	2.22	2.48	2.72	0.3	0.8
Z	53	− 3.5	6	2	0.82	1.10	1.47	1.73	1.90	2.05	2.28	0.6	2.0

ABSORPTION DATA

In previous studies of galactic structure by means of star counts it has been customary to derive the space density of a given region by using a near-by "normal" or unobscured area for comparison. In Cepheus, however, such a plan could not be followed, since a thorough survey of the available material on the distribution of galaxies and the colors of early-type stars showed that no part of the field could be assumed as unobscured.

Table 5 summarizes the Harvard data on the distribution of galaxies as it pertains to the Cepheus field. The material was derived by Dr. Shapley and his collaborators from plates taken with the 16-inch Metcalf telescope at Oak Ridge. A 3-hour exposure reaches the eighteenth magnitude, and the countable area on each plate is about 34 square degrees. Together with the center of the plates, the table gives the actual number of galaxies counted and a tentative value of the total space absorption computed from the relation suggested by Shapley and Boyd.[4]

In the present investigation the Mount Wilson counts of galaxies taken from Hubble's[5] "Distribution of Extragalactic Nebulae" were in general disappointing, because on the 14 centers within this area only 39 nebulae were actually counted. When these were reduced to the number that would have been counted under the "standard" conditions of telescope, declination, exposure time, and plate quality in the manner described in the

TABLE 5

ESTIMATES OF THE TOTAL ABSORPTION IN DIVISIONS OF CEPHEUS FROM HARVARD GALAXY COUNTS

CENTER OF PLATE		TOTAL NEBULAE COUNTED	ESTIMATED ABSORPTION A	CEPHEUS DIVISION
b	l			
+18°	83°	38	2^m1	+17.5° zone
+17	63	171	1.2	V
+16	87	35	2.4	+15.0° zone
+15	77	34	2.2	L
+12	81	20	2.8	+12.5° zone
+12	66	27	2.6	V
+12	62	63	1.9	V
+10	87	50	3.0	R
+ 7	64	5	3.6	H 1
− 3	62	7	3.6	D
− 4	55	12	3.0	C 1
− 8	68	17	2.9	− 7.5° zone
− 9	60	63	2.0	−10.0° zone
− 9	73	20	2.8	−10.0° zone
−12	65	42	2.2	−12.5° zone
−14	70	60	2.0	−15.0° zone

source of the data, then absorptions were computable for only 4 of the centers. These values were 1^m2 for the −10° zone and division M, and 1^m0 for the −15° zone. In all the other cases it was assumed, according to Oort,[6] that a minimum absorption of 1^m7 was indicated. Small weight was given these data in the actual derivation of the densities for the various regions, since the natural uncertainty in the counted numbers made the estimates of the absorption practically indeterminate.

Fortunately, additional estimates of the amounts of space absorption in the various Cepheus divisions could be made from color material. By far the most useful, because of their reliability and general spacing over the field, were the photoelectric colors of 125 early-type stars taken from the list given by Stebbins, Huffer, and Whitford.[7] In the transfer of the color excesses to total photographic absorptions the conversion equation

$$A_{pg} = 9E ,$$

[4] *Harvard Ann.*, **105**, No. 13, 1937.

[5] *Ap. J.*, **79**, 8, 1934; *Mt. W. Contr.*, No. 485.

[6] *B.A.N.*, No. 308, 1938.

[7] *Ap. J.*, **91**, 20, 1940; *Mt. W. Contr.*, No. 621.

given by Stebbins, Huffer, and Whitford,[8] was used; and their spectrum-absolute magnitude relations, corrected for absorption, gave the individual distances of these stars.

In Table 6 the results of these computations, entered as means for the stars in a single Cepheus division, are given.

Of the four Selected Areas 2, 18, 41, and 42, which are in the Cepheus field, all except Area 42 are located in regions where variable reddening may be expected.

In Selected Area 2 ($l = 88°$, $b = +13°$) Bok and Swann[9] found a mean color excess of $+0^m.17$ for the 124 stars measured, which indicated a total photographic absorption of the order of $0^m.7$ per kiloparsec. Seares[10] arrived at a mean excess of +0.55 for 9 stars in the same area. Evidently these stars are located in the heavier obscuration, designated in this paper as region "S," which appears to run across the southern part of Selected Area 2.

TABLE 6

ABSORPTIONS DERIVED FROM PHOTOELECTRIC COLORS

Division	No. of Stars	Mean Distance (Parsecs)	Mean Photographic Absorption	Division	No. of Stars	Mean Distance (Parsecs)	Mean Photographic Absorption
Zone:				*Region (cont.):*			
− 7.5°	4	790	$0^m.5$	H 1	8	630	$2^m.3$
−10.0	3	300	0.4	H 2	1	630	1.1
−12.5	3	330	0.3	J	7	1380	1.8
−15.0	4	370	0.4	K	1	360	0.7
				M	1	1600	2.5
Region:				M	2	630	0.5
A	4	1000	2.3	N	6	470	0.8
A	12	450	1.0	Q	1	260	2.2
C 1	3	640	0.5	R	3	420	0.5
C 2	4	690	0.7	T	5	600	2.1
D	6	860	1.1	T	6	1020	3.0
E 1	7	800	1.2	V	1	630	0.4
E 2	19	790	1.4	W	2	600	3.1
E 3	4	420	0.2	X	1	360	3.0
F	4	430	0.3	Y	3	690	1.8

The available data for Selected Area 18 ($l = 68°$, $b = +7°$) have been summarized by Bok.[11] This material indicated that no reddening was present for distances less than 700 parsecs from the sun. Since this area is almost surrounded by regions of heavier obscuration, it is not surprising to find that the photoelectric colors, averaged over a somewhat larger area, show considerable reddening in the same distance range. Better agreement is obtained for greater distances, between 700 and 2000 parsecs, where the average colors derived from the magnitudes are represented by a total photographic absorption of $1^m.1$ per kiloparsec. Seares[10] called this area a "normal" region on the basis of 10 stars which he found to have an average color excess of only $+0^m.03$.

The star counts outline a band of obscuration which affects the northern part of Selected Area 41 ($l = 61°$, $b = -8°$). It was in this area that Oort[6] found a considerable discrepancy between the absorption estimated from Hubble's nebular counts and from color excesses dependent on Parkhurst's[12] photovisual magnitudes. It seems probable

[8] *Ap. J.*, **90**, 209, 1939; *Mt. W. Contr.*, No. 617.

[9] *Harvard Ann.*, **105**, No. 18, 1937.

[10] *Proc. Nat. Acad. Sci.*, **22**, 327, 1936.

[11] *Ap. J.*, **90**, 249, 1939; *Harvard Reprints*, No. 180.

[12] *Yerkes Pub.*, **4**, 6, 1927.

that a deviation in field centers might be one of the causes. Karpov[13] has provided more recent color material on Selected Area 41, which he kindly loaned in advance of publication. Using a procedure similar to that of Bok and Swann,[9] color excesses in a field 75′ in radius have been measured. Since the absorption was found to be irregular, the colors have been divided as follows:

Distance Interval	Color Excess (Number of Stars)	
	Clear	Obscured
To 1100 parsecs	-0^m02 (67)	$+0^m07$ (47)
1100–1500 parsecs	+0.06 (79)	+0.30 (39)

Selected Area 42 ($l = 70°$, $b = -13°$) is one among those chosen by W. Becker[14] for a study of interstellar reddening. The resulting color excesses are tabulated according to distance intervals and the number of stars involved, as shown below:

Distance Interval	Color Excess (Number of Stars)
80–180 parsecs	-0^m02 (.5)
220–1000 parsecs	+ .34 (46)
1050–2800 parsecs	+0.54 (26)

The majority of the previous studies of the Milky Way in Cepheus have been spectrophotometric investigations centered on regions at galactic longitude 70° and between galactic latitudes +7° and −12°. By far the most extensive of these is the work of Schalén, who in a series of papers[15] has given the distribution of stars according to spectral type in both the dark and bright parts of this area. From these data he has deduced the existence of three dark nebulae for which he has determined the distances and absorptions. His results and their relation to the present investigation may be tabulated as follows:

Schalén's Divisions	Area (Square Degrees)	Number of Dark Nebulae	Total Absorption	Distance (Parsecs)	Star-Count Regions
Nb	19.6	2	$\{0^m3, .6\}$ 0^m9	{250, 410}	E 1, E 2
Nd	19.6	3	{.3, .6, 0.6} 1.5	{250, 410, 800}	H 1, A
Sb	19.3	.....	.....	.....	M
Sd	19.3	.....	.....	.....	J
S_1	36.0	.....	.....	.....	{K, −7.5°, −10.0°, −12.5° zones

Schalén's conclusions have been confirmed by Miss Berg,[16] whose work covered only about 7 square degrees centered at $l = 67°$, $b = +3°$, but which reached to the fifteenth

[13] *Pub. A.A.S.*, **10**, 166, 1942.

[14] *Zs. f. Ap.*, **17**, 285, 1939.

[15] *Upsala Medd.*, No. 37, 1928; No. 50, 1930; No. 55, 1932; No. 58, 1934.

[16] *Poulkovo Bull.*, **15**, No. 2, 1936.

magnitude. Her results show a total absorption of $0^m.9$ between 250 and 450 parsecs and an additional $1^m.1$ between 800 and 1150 parsecs.

In 5 regions of 9 square degrees each, which coincide in part with Schalén's Nd, Nb, and S, Sticker[17] has worked to the eleventh magnitude. He finds that his observed colors may be accounted for by the assumption of a uniform layer of obscuring material, absorbing $1^m.0$ per kiloparsec, which extends from our immediate neighborhood to a distance of several thousand parsecs. Superimposed on this is an absorption of $0^m.5$ from a foreground cloud between 150 and 250 parsecs from the sun.

Two of the Cambridge proper-motion regions which Stenquist[18] has studied for selective absorption are of special interest in the Cepheus analysis. No reddening is found between 500 and 1400 parsecs at $l = 70°$, $b = +3°$, nor between 200 and 800 parsecs at $l = 72°$, $b = 0°$.

The most recent of the spectrophotometric studies have been the investigation of Vanäs[19] of 96 square degrees centered on the Northern Coalsack and that by Wernberg[20] of approximately 130 square degrees centered at $l = 74°$, $b = +3°$. The methods and material are comparable to those used by Schalén except that here the spectra are classified after they have been registered in a photometer rather than by direct estimates. Detailed bibliographies of the two regions, together with charts which show the distribution of the stars according to spectral class and apparent photographic magnitude, will be of considerable use as guides to future work in these fields.

Vanäs concludes from his data that the Northern Coalsack can best be accounted for by two nebulae. The first represents the core and covers about 9 square degrees with an absorption of $1^m.0$ at a distance of 250 parsecs. The second, which is much more extensive, absorbs $1^m.0$ over an area of approximately 43 square degrees and is located at a distance of 630 parsecs. The discrepancy between this value of $2^m.0$ and the value $3^m.5$ found by Miller[21] from faint star counts was taken to indicate that considerable absorption must occur beyond the reach of the material on which the spectrophotometric study was based. Later Miller[22] pointed out that the general practice of averaging the number of bright stars over a large area to obtain sufficient data for the analysis by luminosity classes might be a large factor in the difference between the results. Furthermore, all the spectrophotometric investigations depend on "normal star numbers" valid for an unobscured area in a neighboring region at the same galactic latitude. It now appears that many of these analyses have been based on false assumptions, so that the absorptions for the dark nebulae studied are minimum values. In the case of Wernberg's discussion, however, the so-called "normal" regions L 2 and L 1 are relatively unobscured. Although his work shows much more delineation of the dark material than is attempted in the present paper, the results agree very satisfactorily in broad outline, as the following comparison readily indicates:

Wernberg Division	Absorption at 900 Parsecs		Risley Division	Wernberg Division	Absorption at 900 Parsecs		Risley Division
	W	R			W	R	
L 1	$0^m.0$	$0^m.4$	K	M 2	$0^m.8$	$1^m.0$	A
L 2	0.0	0.8	E 1	M 3	1.1	1.3	J
M 1	1.3	1.0	A	M 4	1.7	1.8	T

Region M 4 is the least certain because of the scantiness of material. A marked discontinuity at 900 parsecs was found in the curve expressing the relation between color

[17] *Bonn Veröff.*, No. 30, 1937.

[18] *Bergstrand Festskrift*, p. 50, 1938.

[19] *Upsala Astr. Obs. Ann.*, **1**, No. 1, 1939.

[20] *Upsala Astr. Obs. Ann.*, **1**, No. 4, 1941.

[21] *Contr. Perkins Obs.*, No. 13, 1939.

[22] *A.J.*, **49**, 174, 1942.

excess and distance, and a value of 1^m7 for the total absorption is assumed at that distance. This amount was derived from an empirical linear relation between selective and total absorption which was set up by Wernberg from data concerning various dark clouds in Cepheus, Cygnus, and Auriga.

Two star-count investigations have been carried out previously in parts of the Cepheus field. In connection with his study of interstellar calcium, O. Struve[23] made counts in two regions covering, in all, some 40 square degrees. The clear region was taken in the so-called "cloud," while the dark nebula was just to the north of $l = 69°$, $b = +2°$. The distance of 350 parsecs and a total absorption of 1^m0 agree well with more recent determinations. The other counts were made by Miss Slocum and Sitterly[24] over an area of 92 square degrees in the vicinity of Selected Area 7. This field overlaps a portion of the heavily obscured division L at the northern border of the Cepheus investigation. Their results give evidence of an irregular cloud of total absorption 1^m0 at a distance of about 500 parsecs. In the calculation of the dimensions and distance of this dark nebula a near-by uniform region was assumed to be "normal." It now seems that such an assumption should be adjusted, since both the Cassiopeia[2] and the Cepheus counts show that this whole northern area is affected, to some extent, by absorption. Bok and Swann's[9] color indices in Selected Area 7 point to the same conclusion.

It appears from all the data which have been presented that the brightest regions in Cepheus, those just south of the galactic plane, are in reality the least obscured, since the light seems not to have been dimmed by more than 1^m0 in 2000 parsecs. Toward the south in the zones of galactic latitudes to $-17.5°$ the absorption averages about 1^m0 at 1000 parsecs from the sun. This amount seems to represent the total absorption at latitude $-17.5°$, but for the zones successively nearer the galactic equator the absorption gradually increases between 1000 and 2000 parsecs until it reaches a total of approximately 2^m0 at latitude $-7.5°$. Since these zones are free from obvious pieces of obscuration, these observations give considerable basis for the assumption of a layer of absorbing material of irregular extent but which is roughly oriented to the galactic plane.

Heavy absorption of at least 3^m0 in 2000 parsecs results from the obscuration just east of the North America nebula and in the Northern Coalsack. A similar condensation of absorbing material is found at $l = 80°$, $b = +16°$. It appears as though the complexity of dark lanes and flares which is so characteristic of Cepheus north of the galactic plane could be the result of absorbing material sweeping out from these particularly opaque sources. Figure 2 has been crosshatched to show the comparative amount of obscuration at 1000 parsecs from the sun in the various Cepheus divisions.

THE SPACE DISTRIBUTION OF THE STARS IN CEPHEUS

Since no unobscured regions could be found in the Cepheus field, the analysis of the star counts has been carried through, using the luminosity and absorption functions which were considered the most reliable ones at that time. The luminosity function is that given by van Rhijn[25] with account taken of his corrections and those of Oort[26] in computing the change of the luminosity with distance from the galactic plane. The values used for the absorption in the various regions were based on the material which was discussed in the previous section.

The papers in this series of "Investigations of Galactic Structure" have expressed the densities resulting from the analysis of the counts in terms of unit density for the vicinity of the sun. This procedure depends on the assumption that the stars for which van Rhijn determined the general luminosity function lie, for the most part, within a sphere 100 parsecs in radius around the sun and that the density within this sphere is equal to unity. For greater distances from the galactic plane corrections must be applied to the luminosity function to take care of the changing proportions and types of the stellar contents of

[23] *Ap. J.*, **65**, 163, 1927; *Mt. W. Contr.*, No. 331.

[24] *Harvard Bull.*, No. 905, 1937.

[25] *Groningen Pub.* No. 47, 1936.

[26] *B.A.N.*, No. 290, 1936.

space. With this particular symbolism for expressing densities away from the galactic plane, values as great as 1.0 would not be expected because of the general decrease in density with increasing distances from the plane. Although the Cepheus analysis has been carried through using the traditional method, it seems desirable in future investigations to follow the suggestion of Dr. Freeman D. Miller and define the densities found from the given luminosity function at various levels, z, above the plane as unity for the respective value of z. In that way there would be less ambiguity in the comparison of density results derived by different methods. Bok and MacRae,[27] in a discussion of stel-

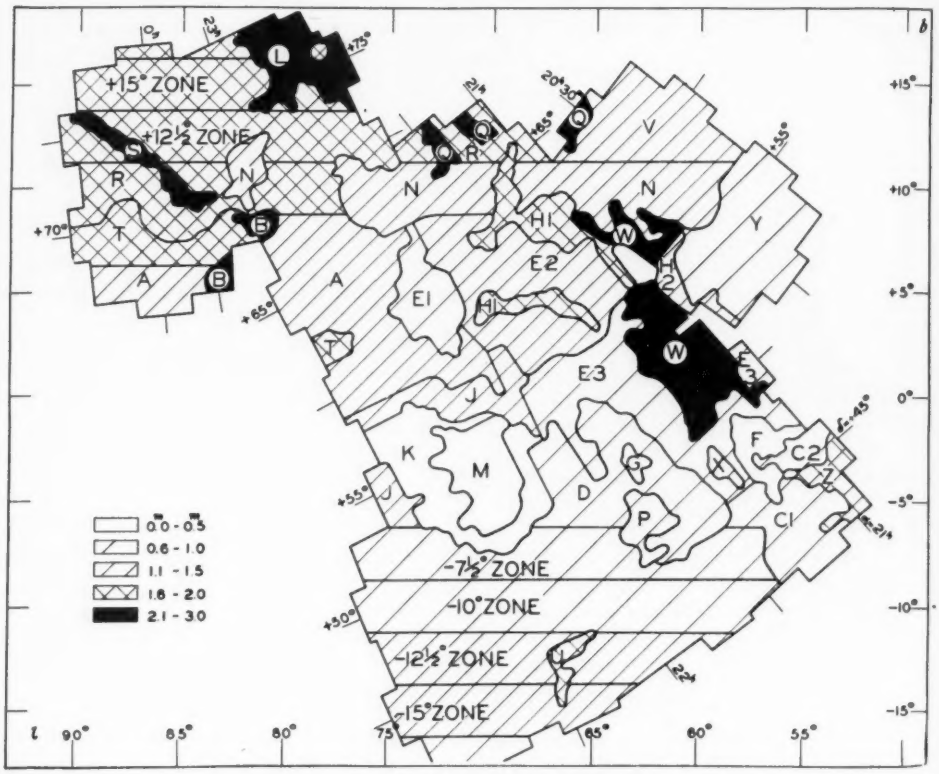

FIG. 2.—Obscuration at 1000 parsecs

lar distribution, have adopted the quantities $D(M, z)$ as measures of the factor by which the actual star densities in a given direction differ from those toward the galactic poles.

Region H 1.—From the data presented in an earlier section of this paper it is evident that most of the previous investigations in Cepheus have been concerned with regions which are partially obscured by obvious dark nebulae. In particular, the region whose center is at $l = 67°$, $b = +3°$, has been studied extensively as the "Cepheus Dark Nebula," and it is probable that the amount and distribution of the absorbing material in this direction is as well determined as anywhere in the Cepheus field. The counts over approximately 23 square degrees have been analyzed by means of the $(m, \log \pi)$ tables, which have been described by Bok.[28] To test the sensitivity of the density function to different distributions of the obscuring material, several solutions for the space densities were made. One of the most probable assumptions for the amount of absorption is 0^m4

[27] *Ann. N.Y. Acad. Sci.*, **42**, 219, 1941.

[28] *Harvard Circ.*, No. 371, 1931.

at 200 parsecs and $1^m.5$ at 800 parsecs—values suggested by the two-cloud interpretation of Schalén. The resulting function (2) is compared in Table 7 with (1) the solution in which no absorption is assumed and (3) the solution with a constant coefficient $A_{pg} = 1^m.9$ per kiloparsec.

It is evident from Table 7 that steep negative-density gradients exist within 2000 parsecs of the sun in this direction and that a constant coefficient of absorption probably minimizes the effect of the absorption on the density function.

TABLE 7

VALUES OF $D(r)$ IN THE "CEPHEUS DARK NEBULA"

r (PARSECS)	$D(r)$			r (PARSECS)	$D(r)$		
	(1)	(2)	(3)		(1)	(2)	(3)
125	1.00	1.00	1.00	800	0.15	0.38	0.40
200	0.75	0.80	0.95	1250	.04	.16	.30
320	0.50	0.72	0.90	2000	0.01	0.05	0.20
500	0.25	0.58	0.75				

Region E 1.—This region, a diamond-shaped area of approximately 15 square degrees at galactic latitude $+5°$, extends from ξ to λ Cephei and appears to be one of the least obscured areas in the Cepheus field north of the galactic plane. The available color data were both meager and poorly spaced, so that the assumed coefficient of absorption was a rough approximation. Two solutions for the density function were made: (1) assuming no absorption, and (2) for a constant coefficient, $A_{pg} = 0^m.9$ per kiloparsec to a distance of 2000 parsecs. The results are shown in Table 8.

TABLE 8

VALUES OF $D(r)$ IN REGION E 1

r (PARSECS)	$D(r)$		r (PARSECS)	$D(r)$	
	(1)	(2)		(1)	(2)
125	1.00	1.00	800	0.28	0.70
200	0.95	1.00	1250	.12	.18
320	0.83	1.00	2000	0.02	0.18
500	0.58	1.00			

More recently, Wernberg's[20] discussion of the region which he designates as L 2 and which coincides in part with region E 1 of the present paper has provided much more dependable values of the absorption in this area. Making use of the color excesses of the very luminous early B-type stars, Wernberg reaches out to distances much greater than 2000 parsecs from the sun. At small distances, however, he finds it difficult to decide whether or not a selective absorption exists; so two assumptions are made regarding the total absorption in this bright area. If the region is free from absorption to 1000 parsecs, then $0^m.33$ per kiloparsec will represent the uniform increase in reddening out to the limit of the observations. If, however, the absorption begins in the immediate neighborhood of the sun, the value becomes $0^m.49$ per kiloparsec at distances beyond 1000 parsecs. In either case this area is conspicuous north of the galactic plane in Cepheus because of its lack of absorption.

From these data it appears that solution (1) in Table 8, which shows a rapid negative-density gradient, is a better approximation than solution (2). Wernberg's apparent space densities for stars of different spectral types also show rapid decreases at small distances from the sun—a phenomenon which he considers probably not real. The density-curves at greater distances show only a slight decrease. A conspicuous feature of Wernberg's density-curves for the early B stars in region L 2 is the maximum at 1300 parsecs, which is interpreted as an indication of a star-cloud. Since the portion of the curve which produces the most pronounced maximum is dependent on less than 10 stars, it may be found that additional data will show either a constant density or even a decrease in density in the distance range between 800 and 1300 parsecs from the sun.

Region M.—One of the most striking portions of the Cepheus field is the bright cloud-like area of approximately 18 square degrees centered at $l = 70°$, $b = -3°$, which has been designated in this paper as region "M." Here the number of stars per square degree of apparent magnitude 15.0 or brighter reaches its maximum value. The region is of particular interest because of its close proximity to the galactic equator and because it is believed to be the least obscured area investigated here. From Hubble's[5] data on the distribution of extragalactic nebulae it was found that 7 nebulae were counted on a Mount Wilson plate centered near the middle of this region. When this number was reduced to "standard" conditions, it became 16, from which the total absorption was estimated as $1^m.2$. Photoelectric colors were available for only 3 stars. Their color excesses, computed distances, and the resulting total photographic absorptions are:

E	r	A_{pg}
+0.07	350 parsecs	$0^m.6$
.04	910	0.4
+0.28	2000	2.5

Again two preliminary solutions for the density function were made: (1) assuming no absorption and (2) with $A_{pg} = 0^m.5$ per kiloparsec for the first 1000 parsecs and then $0^m.2$ per kiloparsec. The results are given in Table 9.

TABLE 9

VALUES OF $D(r)$ IN REGION M

r (PARSECS)	$D(r)$		r (PARSECS)	$D(r)$	
	(1)	(2)		(1)	(2)
125	1.00	1.00	800	0.50	0.74
200	1.00	1.20	1250	.12	.35
320	1.00	1.20	2000	0.08	0.15
500	1.00	1.20			

Two problems are suggested by these solutions. The first is an investigation of the reality of the density increases near the sun. Since it is found that other regions south of the galactic equator share the tendency to yield densities in excess of 1.00 to 500 parsecs, the discussion will be continued after all the density functions have been tabulated. It is also of interest to consider the type of absorption function which would be necessary to produce a constant density in a given direction. Accordingly, an $(m, \log \pi)$ table was set up for galactic latitude $-3°$, and a constant unit density was assumed. A very satis-

factory agreement between the observed and theoretical star numbers at the different apparent magnitudes was found for the following values of the total absorption:

r.....	200	650	1000	1250	2000	3000	parsecs
A_{pg}.....	0^m0	0^m0	1^m0	1^m6	2^m3	3^m2	

On the basis of the available absorption data this hypothesis of constant density remains one of the possible solutions.

Wernberg's[20] other bright region, L 1, corresponds to K of this paper, which, in turn, surrounds the brighter region M. In L 1 Wernberg finds that the densities of stars of different spectral types exceed in general those in L 2, with the effect most pronounced for the A stars. The space-density-curves corrected for 0^m33 per kiloparsec absorption beyond 1000 parsecs, as in region L 2, show the same rapid decrease for a few hundred parsecs, followed by slight decreases at greater distances from the sun. The early B stars also show the rapid decrease in density to about 900 parsecs, after which there is a slight increase and then an approximately constant density to the limit of the observations.

Other Cepheus divisions.—At the present time the lack of spectral, color, and galaxy data in the remaining Cepheus divisions makes possible only approximate solutions for the density functions. For each of the zones and regions two solutions were made by means of the (m, log π) tables. In the first of these solutions the star densities were determined on the basis of no obscuration—an assumption which certainly appears incorrect in the light of the available absorption data. The solution was carried out, however, because it gave an opportunity to see the effect of the absorption on the density functions as well as to provide the tables, which can be converted easily into new density functions as additional material concerning a given region makes possible a more reliable estimate of the absorption. These densities appear as Table 10, where they are given as functions of galactic latitude and distance from the sun. The second solution was based, in general, on the assumption of a constant coefficient of absorption. For each Cepheus division points were plotted, which represented the total photographic absorption at computed distances from the sun, as derived from the absorption data discussed in a previous section of this paper. The greatest effectiveness of the obscuration was assumed to take place in a layer of absorbing material 300 parsecs in half-thickness oriented symmetrically to the galactic plane. In most cases a single straight line, representing a constant coefficient of absorption from the neighborhood of the sun to the distance at which the absorbing layer ceases to be effective, was as satisfactory an assumption as could be made with the present data. From the resulting curves the total obscurations at different distances from the sun have been derived and are given in Table 11. The material has been arranged to make easily comparable regions of similar obscuration at 1000 parsecs from the sun. A finer subdivision is shown graphically in Figure 2.

Table 12 gives the density functions which were derived using the adopted values of the absorption. From Tables 10 and 12 two conclusions are immediately evident. In the first place, regardless of the different assumptions made concerning the amount of absorption, and independent of the location of the region in the Cepheus field, the densities show marked negative gradients with values at 1000 parsecs from the sun not more than one-third of the unit density assumed at the sun. The inclusion of the absorption coefficient in the solution for the density function seems only to move out several hundred parsecs the distance at which the steep density decreases commence. The more interesting result, however, is the tendency in many of the regions south of the galactic plane for the space densities to increase for a few hundred parsecs from the sun and then to fall sharply as in the other divisions.

Following the preliminary solutions for the density functions in Cepheus, the most obvious problem was the investigation of these density increases, within 500 parsecs of the sun, which were found in the regions south of the galactic equator.

TABLE 10

DENSITIES AS FUNCTIONS OF GALACTIC LATITUDE FOR NO OBSCURATION

r (Parsecs)	b							
	−17.5°	−15°	−12.5°		−10°	−7.5°	−5°	
			Zone	U			C 1	P
125	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
200	0.84	0.90	0.95	0.90	1.00	1.00	1.00	0.90
320	0.60	0.80	0.90	0.50	1.00	1.00	1.00	0.70
500	0.47	0.55	0.75	0.30	0.90	1.00	1.00	0.60
800	0.30	0.36	0.27	0.09	0.30	0.34	0.25	0.20
1250	0.09	0.05	0.08	0.03	0.15	0.18	0.04	0.10
2000	0.01	0.02	0.02	0.02	0.03	0.03	0.01	0.05

r (Parsecs)	b							
	−2.5°							
	K	M	G	D	C 2	F	Z	X
125	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
320	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	0.80	1.00	0.30	0.80
800	0.30	0.50	0.75	0.50	0.30	0.90	0.02	0.02
1250	0.10	0.12	0.25	0.05	0.05	0.05	0.01	0.01
2000	0.05	0.08	0.02	0.01	0.01	0.01	0.01	0.01

r (Parsecs)	b						
	0°		+2.5°	+5°			
	E 3	J	W	A	E 1	E 2	H 2
125	1.00	1.00	1.00	1.00	1.00	1.00	1.00
200	0.90	0.95	0.95	0.84	0.95	0.95	0.70
320	0.70	0.90	0.90	0.50	0.83	0.78	0.40
500	0.50	0.40	0.10	0.30	0.58	0.40	0.30
800	0.16	0.20	0.02	0.18	0.28	0.15	0.15
1250	0.01	0.05	0.01	0.05	0.12	0.08	0.03
2000	0.01	0.03	0.01	0.01	0.02	0.02	0.01

r (Parsecs)	b						
	+7.5°			+10°			
	B	Y	T	H 1	N	R	S
125	1.00	1.00	1.00	1.00	1.00	1.00	1.00
200	0.85	0.95	0.95	0.75	0.90	0.70	0.80
320	0.65	0.90	0.65	0.50	0.80	0.50	0.50
500	0.12	0.66	0.28	0.25	0.55	0.30	0.16
800	0.02	0.40	0.03	0.15	0.28	0.20	0.04
1250	0.01	0.16	0.01	0.04	0.08	0.10	0.02
2000	0.01	0.01	0.01	0.01	0.01	0.02	0.02

TABLE 10—*Continued*

r (Parsecs)	b					
	+12.5°			+15°		+17.5°
	Zone	Q	V	L	Zone	
125	1.00	1.00	1.00	1.00	1.00	1.00
200	0.84	0.84	0.90	0.84	0.90	0.84
320	0.65	0.65	0.80	0.50	0.65	0.65
500	0.37	0.28	0.61	0.05	0.46	0.30
800	0.11	0.03	0.33	0.02	0.18	0.13
1250	0.05	0.02	0.01	0.01	0.05	0.02
2000	0.01	0.02	0.01	0.01	0.02	0.01

TABLE 11

TOTAL OBSCURATION AT DIFFERENT DISTANCES FROM THE SUN

b (Degrees)	Region	Distance in Parsecs					
		200	300	500	800	1000	2000
−17.5		0^m.2	0^m.3	0^m.5	0^m.8	1^m.0	1^m.0
−10		.2	.3	.5	0.8	1.0	1.8
0, −5	E 3, P	.2	.3	.5	0.8	1.0	2.0
+5	A, E 2, H 2	.2	.3	.5	0.8	1.1	2.1
+10	N	.2	.3	.5	0.9	1.1	2.0
−12.5		.2	.3	.5	0.9	1.2	1.7
+12.5	V	.0	.0	.2	0.8	1.2	1.9
−2.5	X	.0	.0	.4	0.9	1.2	3.0
−15		.2	.3	.6	1.0	1.3	1.5
0	J	.3	.5	.8	1.2	1.5	3.0
+15		.3	.4	.8	1.2	1.6	2.0
+10	R	.3	.5	.8	1.3	1.7	3.0
+17.5		.3	.5	.9	1.4	1.8	1.8
+10	H 1	0.4	0.6	0.9	1.5	1.9	3.6
− 2.5	G	0.1	0.1	0.2	0.3	0.4	0.8
− 2.5	M	.1	.1	.2	.4	.5	0.7
− 2.5	F, K	.1	.2	.2	.4	.5	1.0
− 2.5	D	.1	.2	.3	.5	.6	1.2
− 2.5	C 2	.1	.2	.4	.6	.7	1.4
− 7.5		.0	.0	.2	.6	.8	2.1
+ 7.5	Y	.2	.3	.4	.6	.8	1.6
+ 5, −5	E 1, C 1	0.2	0.3	0.4	0.7	0.9	1.8
+12.5, −12.5	U	0.4	0.6	1.0	1.6	2.0	2.8
+ 7.5	T	.4	0.6	1.0	1.6	2.0	3.0
− 2.5	Z	.4	0.6	1.0	1.6	2.0	4.0
+12.5	Q	.5	0.7	1.1	1.8	2.2	3.0
+10	S	.5	0.7	1.1	1.8	2.2	3.5
+ 7.5	B	.5	0.7	1.2	2.0	2.5	2.5
+15	L	.6	0.9	1.5	2.4	3.0	3.2
+ 2.5	W	0.6	1.0	1.5	2.4	3.0	4.0

TABLE 12

DENSITIES AS FUNCTIONS OF GALACTIC LATITUDE FOR ADOPTED VALUES OF ABSORPTION

r (PARSECS)	b							
	−17.5°	−15°	−12.5°		−10°	−7.5°	−5°	
			Zone	U			C 1	P
125	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.10	1.30	1.00	1.30	1.30	1.50	1.00
320	1.00	1.10	1.30	1.00	1.30	1.30	1.50	1.00
500	1.00	1.10	1.30	0.90	1.30	1.30	1.50	1.00
800	0.41	0.74	0.60	0.38	0.88	0.90	0.40	0.70
1250	0.12	0.15	0.25	0.34	0.30	0.35	0.08	0.20
2000	0.04	0.05	0.20	0.30	0.25	0.35	0.07	0.05

r (PARSECS)	b							
	−2.5°							
	K	M	G	D	C 2	F	Z	X
125	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.20	1.30	1.30	1.50	1.50	1.50	1.20
320	1.00	1.20	1.30	1.30	1.50	1.50	1.50	1.20
500	1.00	1.20	1.30	1.30	1.00	1.50	0.86	0.80
800	0.70	0.74	1.00	0.64	0.47	0.70	0.05	0.10
1250	0.30	0.35	0.30	0.20	0.12	0.14	0.01	0.05
2000	0.20	0.15	0.10	0.10	0.11	0.10	0.01	0.05

r (PARSECS)	b						
	0°		+2.5°	+5°			
	E 3	J	W	A	E 1	E 2	H 2
125	1.00	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.00	1.30	1.00	1.00	1.00	0.95
320	1.00	1.00	1.30	1.00	1.00	1.00	0.90
500	1.00	1.00	1.00	0.50	1.00	0.80	0.50
800	0.40	1.00	0.05	0.22	0.70	0.40	0.20
1250	0.09	0.40	0.04	0.20	0.18	0.20	0.10
2000	0.02	0.20	0.03	0.20	0.18	0.20	0.08

r (PARSECS)	b						
	+7.5°			+10°			
	B	Y	T	H 1	N	R	S
125	1.00	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.10	1.00	0.95	1.00	1.00	0.90
320	0.95	1.10	1.00	0.90	1.00	1.00	0.82
500	0.54	1.10	0.70	0.75	1.00	0.90	0.60
800	0.12	0.90	0.25	0.40	0.70	0.62	0.30
1250	0.05	0.20	0.08	0.30	0.10	0.36	0.15
2000	0.01	0.03	0.05	0.20	0.01	0.20	0.10

TABLE 12—*Continued*

r (PARSECS)	b					
	+12.5°			+15°		+17.5°
	Zone	Q	V	L	Zone	
125	1.00	1.00	1.00	1.00	1.00	1.00
200	1.00	1.00	1.00	1.00	1.00	1.00
320	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	0.80	1.00	0.50	1.00	1.00
800	0.30	0.50	0.60	0.10	0.65	0.25
1250	0.15	0.10	0.12	0.05	0.13	0.05
2000	0.10	0.01	0.10	0.05	0.10	0.01

SPECTRAL DISTRIBUTION

Adequate spectral material was available in Selected Areas 41 and 42. The former is centered at galactic latitude $-8°$ and includes parts of regions P and D and the $-7.5°$ zone, while Selected Area 42 falls within the $-12.5°$ zone. In order that the statistics of the spectral distribution in the immediate vicinity of the sun should be as complete as possible, counts from magnitude 4.25 to 6.75 corrected to photographic magnitude were taken from Seydl's[29] tabulation of the number of stars of the various spectral classes in the *Henry Draper Catalogue*. The counts are given for the zone of galactic latitude between $+10°$ and $-10°$, averaged over all longitudes. Additional counts for stars brighter than $m_{pg} = 8.5$ were made in the same catalogue for spectral divisions B8–A0 and A1–A7 over a region of approximately 50 square degrees centered on each of the two selected areas. Finally, the *Bergedorfer Spektral-Durchmusterung* supplied the faintest counts, to $m_{pg} = 11.5$, over the same spectral ranges and covering an area of about $12\frac{1}{4}$ square degrees.

These data were then expressed in terms of $A'(m)$, i.e., the number of stars of apparent magnitude between $m-\frac{1}{4}$ and $m+\frac{1}{4}$ reduced to an area of 100 square degrees. The adopted values of log $A'(m)$ for Selected Areas 41 and 42 follow, as Table 13. These values were determined from smooth curves drawn through points which represented the respective log $A'(m)$ for a given apparent magnitude as derived from the sources mentioned.

The counts have been analyzed by the Lindblad-Schalén method. The mean absolute magnitudes used were $M = +0.5$ for the B8–A0 stars and $M = +2.0$ for the A1–A7 stars, with a dispersion $\sigma = \pm 1^m.0$ assumed for both spectral divisions. The corrections for absorption, made with the use of Seeliger's formula, were based on an assumed total photographic absorption, $A_{pg} = 0^m.8$ per kiloparsec for Selected Area 41 and $A_{pg} = 1^m.3$ per kiloparsec in Selected Area 42. In the resulting density functions, which are given in Table 14, the space density at 100 parsecs from the sun has been taken as 1.00.

Clearly the density gradients for the early-type stars are much steeper than for the stars as a whole. It is of particular interest, however, that near the galactic equator the density increase in the neighborhood of the sun persists, especially for the A stars. It is possible, of course, that some of the increase might be due to irregularities in the spectral classification.

In his *Researches on the Structure of the Universe*, Pannekoek[30] has investigated the space distribution of the stars of different spectral types derived from the *Henry Draper Catalogue*. Some of his results are given in charts on which are outlined regions of high density within a layer bounded by planes 30 parsecs above and below the galactic equator. These charts show that an irregular area of high A-star density reaches over the Cyg-

[29] *Pub. Nat. Obs. Prague*, No. 6, 1929.

[30] *Amsterdam Pub.*, **2**, 1929.

nus border and extends from 75 parsecs to the observational limit at 300 parsecs. The presence of this area of high density is confirmed by the careful study of Malmquist and Hufnagel,[31] who have based their results on the same material as that used by Panne-

TABLE 13

ADOPTED VALUES OF LOG $A'(m)$

m_{pg}	Spectrum			
	Selected Area 41		Selected Area 42	
	B8–A0	A1–A7	B8–A0	A1–A7
4.25	9.30	9.40	9.30	9.40
4.75	9.68	9.54	9.68	9.54
5.25	0.03	9.78	0.03	9.78
5.75	0.39	9.97	0.39	9.97
6.25	0.70	0.22	0.70	0.22
6.75	1.05	0.46	1.03	0.46
7.25	1.36	0.82	1.26	0.75
7.75	1.58	1.15	1.41	1.06
8.25	1.73	1.41	1.55	1.30
8.75	1.87	1.69	1.70	1.53
9.25	1.98	1.94	1.84	1.76
9.75	2.03	2.20	1.96	1.95
10.25	2.07	2.45	2.03	2.17
10.75	2.18	2.64	2.12	2.33
11.25	2.18	2.86	2.19	2.51

TABLE 14

RELATIONS BETWEEN SPACE DENSITIES AND DISTANCE FROM THE SUN

r (PARSECS)	$D(r)$					
	Selected Area 41			Selected Area 42		
	B8–A0	A1–A7	General Star Counts	B8–A0	A1–A7	General Star Counts
100	1.00	1.00	1.00	1.00	1.00	1.00
200	1.20	1.26	1.20	1.02	0.89	1.20
300	0.69	1.34	1.20	0.64	0.64	1.20
400	0.48	1.13	1.20	0.41	0.45	1.20
500	0.34	0.82	1.20	0.24	0.32	1.20
600	0.24	0.58	1.08	0.16	0.24	1.05
700	0.17	0.37	0.94	0.11	0.17	0.87
800	0.12	0.21	0.75	0.08	0.12	0.67
900	0.08	0.12	0.61	0.06	0.10	0.51
1000	0.06	0.10	0.48	0.05	0.09	0.39

koek. They have taken account of the dispersion in absolute magnitude of the A stars, however, which reduces the limiting distance for which the densities are given to 150 parsecs.

[31] *Stockholm Obs. Ann.*, **11**, No. 9, 1933.

Similar evidence that this region is affected by a condensation of A stars comes from Humason's[32] study of the spectral types of faint stars to $13^{m}.6$ in Selected Area 41. Of the 76 stars whose spectra were classified, approximately one-third were A stars, which is about 60 per cent more than the expected number at this galactic latitude.

The faintest spectra which have been determined in the Cepheus field are the result of the work of Fr. Tibor,[33] who has classified over 2000 stars down to $14^{m}.0$ in an area of 4 square degrees centered at $l = 69.3°$, $b = -2.5°$. This was the first of several regions which Fr. Tibor studied, but unfortunately we have available only a synopsis of the results. A communication from Fr. Stein tells of the continuation of Fr. Tibor's work by Fr. Junges and assures us that the material for Cepheus-Lacerta region will eventually be published. The most striking feature of the diagram which Fr. Tibor presented to summarize the spectral distribution in the field is the large percentage of A stars brighter than $12^{m}.0$. Even at $13^{m}.0$ the number of A stars exceeds those in any other spectral group, and only at $14^{m}.0$ is there a change in the maximum, and then the decrease is small. This result is at variance with the investigations of the distribution of spectra in the *Henry Draper Catalogue* by Shapley, in the *Bergedorfer Spektral-Durchmusterung* by Schwassmann, and in Selected Areas 1–115 by Humason, which have agreed in showing that the relative number of G stars increased with decreasing brightness.

All these data point to a definite deviation from a "normal" stellar distribution throughout the area south of the galactic equator in Cepheus. The only conclusion that can be made at the present time is that the general luminosity function and a constant coefficient of absorption are very poor approximations in this part of the Cepheus field and that the reality of the density increases must depend on additional data concerning spectra and colors of stars in this region.

THE EFFECT OF SMALL-SCALE IRREGULARITIES ON GENERAL STAR COUNTS

Some years ago Pannekoek[34] called attention to the danger of deriving erroneous results from the analysis of star counts in fields where the distribution of absorbing material was patchy.

In the Cepheus investigation every effort was made to map the field in such a way that these regions of mixed spacity could be avoided. Realizing, however, that some regions of mixed absorption probably do occur, a study was made of the extent and effect of such irregularities.

Two types of counts were made: (1) stars in the *Mount Wilson Catalogue* for Selected Areas 2, 8, 18, 19, 41, and 42 were plotted and then counted in area units $1' \times 1'$; (2) using a quarter-centimeter *réseau*, with an area unit $12' \times 12'$, counts were made in the centers of 9 RL Cepheus plates. For 7 of the regions chosen approximately 4 square degrees were counted on the RL centers, and for the other two the area covered was about 23 square degrees.

Since Poisson's exponential function,

$$f(x) = \frac{m^x e^{-m}}{x!},$$

was used to find the probability of obtaining exactly x stars in any chosen square, the expected frequency distribution of the values of x was derived from the relation

$$n(x) = n e^{-m} \frac{m^x}{x!}.$$

The χ-square test was then applied to determine the probability, P, that a distribution as improbable or less probable than the observed one could have arisen by chance fluctua-

[32] *Ap. J.*, **76**, 224, 1932; *Mt. W. Contr.*, No. 458.

[33] *Acta della Pontifica Accad. delle Sci.*, **1**, 85, 1937.

[34] *Pub. Amsterdam*, **1**, 1924.

tions in sampling. The details of the use of this method in the study of star counts has been described by Sterne.[35] The results of these calculations, together with the approximate value of the absorption at 2000 parsecs for each of the areas investigated, are given in Table 15.

From the values of P it appears that the counts in the small fields of the Selected Areas show no significant deviations from random distribution. In the selection of the 9 regions care was taken to choose homogeneous fields for only the first 4 centers. The effect of the intermingling of dark and bright fields, or the significant departure from a random distribution, is shown by the low values of P for the other regions. The border case, where $P = 0.01$, is of particular interest, since this region is apparently the brightest part of the field, designated as "M" in the Cepheus divisions. Several possibilities are open for further investigation. Absorption, though certainly not obvious, may affect the fainter stars in M, or the deviation from random distribution may be due at least in part to variations in the luminosity function.

TABLE 15

SMALL-SCALE IRREGULARITIES IN STAR COUNTS

1. MOUNT WILSON SELECTED AREAS

Field	P	Absorption at 2000 Parsecs	Field	P	Absorption at 2000 Parsecs
2	0.3	1^m4	19	0.1	1^m7
8	.1	2.4	41	.3	2.0
18	0.6	2.1	42	0.9	2.2

2. CEPHEUS REGIONS

Field		P	Absorption at 2000 Parsecs	Field		P	Absorption at 2000 Parsecs
α	δ			α	δ		
20^h30^m,	$+55°$	0.9	1^m6	21^h20^m,	$+50°$	$<10^{-6}$	4.0
20 30 ,	60	0.4	2.0	0 00 ,	70	$<10^{-6}$	3.2
22 50 ,	45	0.2	1.6	0 00 ,	75	$<10^{-6}$	3.2
22 30 ,	55	0.01	0.7	22 30 ,	+60	$<10^{-6}$	2.5
21 30 ,	+60	$<10^{-6}$	3.6				

As a rough test of the sensitivity of the value of P to the effect of absorption, several hypothetical clouds were superimposed on the field at $\alpha = 20^h30^m$, $\delta = +55°$, a region which is not free from absorption but where the material appears to be evenly distributed. The counts were reduced in the following way: (1) for heavier uniform absorption to cover the whole region, the star numbers in each area unit were divided by 2.5; (2) for a cloud which covers one-half of the region but leaves the other part unchanged, the star numbers were reduced in the ratio 2.5:1; and (3) for a wedge-shaped cloud the star numbers were decreased gradually across the region by factors of 2.5, 2.0, 1.5, 1.2, and 1.

The original value of P for this region was 0.9. With additional absorption of the first type superimposed, that value was reduced to 0.002, and for the other absorption models P was found to be less than 10^{-6}. These results may be taken as another definite indication that stars in fields of mixed absorption show strong departures from random distribution. The chance of obtaining such deviations is considerably reduced, however, where care has been taken to divide the field into homogeneous units of sufficient size so that the number of stars to be analyzed is large enough to make the results statistically stable.

[35] *Harvard Circ.*, No. 396, 1934.

SUMMARY AND CONCLUSIONS

Star counts to magnitude 15.0 have been made on plates taken with the 4-inch Ross-Lundin camera over an area of 750 square degrees in Cepheus. Errors to which the counts are subject have been investigated and were found to be satisfactorily small for all but the faintest limit counted. A comparison with the *Durchmusterung* counts indicated the need of a correction of +0.04 in log $N(m)$ at magnitude 15.0. The values of log $N(m)$ have been computed for homogeneous areas into which the field has been divided for purposes of analysis.

The available information concerning the absorbing and scattering power of the dark material in this direction showed that no part of the area investigated could be considered unobscured. It appears, however, that the brightest regions in Cepheus, those just south of the galactic plane, are in reality the least obscured, since there seems to be not more than $1^m.0$ absorption in 2000 parsecs. Farther south, in the uniform zones, observations of the amount of absorption give considerable basis for the assumption of an irregular layer of absorbing material roughly oriented to the galactic plane. The most effective width of this layer is between galactic latitudes $+10°$ and $-10°$, where the total absorption probably does not exceed $1^m.0$ per kiloparsec. Heavy absorption of at least $3^m.0$ in 2000 parsecs results from the obscuration just east of the North America nebula and in the Northern Coalsack. A similar condensation of absorbing material is found at $l = 80°$, $b = +16°$. The complexity of dark lanes and flares which is so characteristic of Cepheus north of the galactic plane might be the result of absorbing material sweeping out from these particularly opaque sources.

The total absorption affecting the various divisions in Cepheus was estimated, and solutions for the densities were made. In most cases a constant coefficient of absorption, starting in the neighborhood of the sun and reaching to the distance at which the absorbing layer ceases to be effective, was as satisfactory an assumption as could be made with the present data. The densities north of the galactic plane are found to be approximately constant for several hundred parsecs, after which they drop sharply. Just south of the plane there is a persistent rise in the densities within 500 parsecs of the sun, but for distances greater than 800 parsecs the density functions are similar to those derived for the northern divisions. The reality and possible causes of this rise in density are discussed.

In order to study the effect of small-scale irregularities on general star counts, several Mount Wilson Selected Areas and certain chosen regions in the Cepheus field were counted in units of small area and analyzed for departure from random distribution. The chance of obtaining such deviations was found to be considerably reduced if the field is divided into homogeneous regions of sufficient size to produce statistically trustworthy data.

From the preliminary survey in Cepheus several comparatively clear regions have been found where color indices of stars of known spectral class would provide a much more reliable solution of the density function. Further investigation has already been started on one of these areas centered at $l = 70°$, $b = -3°$, and designated in this paper as region "M." The total absorption in this direction probably does not exceed $0^m.7$ out to a distance of 2000 parsecs. Recently the writer has classified the spectra of approximately 5000 stars to magnitude 12.5 over about 80 square degrees in this part of the Cepheus field. The classification was done at McCormick Observatory under the direction of Dr. A. N. Vyssotsky. For many of these stars work has also been commenced on the color excesses, which are being determined from blue and red photometric comparisons on plates loaned by Harvard Observatory.

In conclusion, I wish to express my gratitude to Dr. Bart J. Bok for his continued interest in this investigation and for his valuable advice and criticism. I am particularly indebted also to Dr. Robert H. Baker and to Dr. Freeman D. Miller for many helpful suggestions.

THE RADIAL VELOCITIES OF FAINT CLASS B STARS IN THE DECLINATION ZONE 0° TO −23°*

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ABSTRACT

The radial velocities of 433 stars of spectral classes Oe5–B5 have been determined at the Lick Observatory on a program of observation which includes all stars of this type in the declination zone 0° to −23° given in the *Henry Draper Catalogue*. For 397 faint stars of the present list no previous determinations of radial velocity have been published. The spectra have been classified on the Victoria system. The program was undertaken in co-operation with the Dominion Astrophysical Observatory.

The observations for the determination of the radial velocities of the fainter B-type stars described in the present paper were undertaken early in 1933 in co-operation with the Dominion Astrophysical Observatory, where stars of this spectral type fainter than magnitude 7.5 and north of the celestial equator were being observed. According to arrangement, the author agreed to secure these data for all stars whose spectra were listed as of classes Oe5–B5 in the *Henry Draper Catalogue* in the zone of declination 0° to −23° for which radial velocities had not been previously determined.

The program consisted of 407 stars within these limits of declination, for 389 of which no prior observations had been made. In addition, 26 stars north of the celestial equator were observed, of which 8 are faint stars without previous observations, 3 are spectroscopic binaries, and 15 are bright B stars with well-determined velocities taken here as a check upon the present measures.

The spectrograms were taken with spectrographs giving linear dispersions at $H\gamma$ of approximately 75 and 140 A per millimeter, used in conjunction with the 36-inch refractor. Two spectrographs of the greater dispersion were employed, one provided with one prism and a camera of 12 inches focal length, the other with two prisms and a 6-inch camera, the former combination being used for stars brighter than magnitude 8.4 and the latter for those between magnitudes 8.4 and 9.4. The lower dispersion was obtained by replacing the 6-inch camera with one of $3\frac{1}{2}$ inches and was used prior to the spring of 1941 for stars fainter than magnitude 9.4. At that time the surfaces of the two prisms and of the elements of the 6-inch camera lens were coated with thin films of lithium fluoride and magnesium fluoride, respectively, by Dr. John Strong, at the California Institute of Technology. The gain in light resulting from the decreased reflection at the coated surfaces permitted a 50 per cent reduction in the exposure times previously required for the two-prism and 6-inch camera. This instrument was therefore employed in subsequent observations of the fainter stars. In this connection it is of interest to note that an exposure time of 2 hours with this combination and an Eastman Spectroscopic Plate 103a0 gives a well-exposed spectrogram of a star of the eleventh photographic magnitude, which is near the limit of brightness for objects of the present program.

A total of 2990 measurable spectrograms was taken by the writer in the interval June, 1933—February, 1942. These have been measured in the usual way with a Toepfer engine by Miss Doris Roosen Raad and the author—1254 by the former and 2089 by the latter—the measures of 353 plates being by both observers. The number of stellar lines measured on each spectrogram in the region λλ 3900–4600 varied from 3 to 17, depending upon the spectral type and the quality of the lines. The wave lengths adopted for the stellar lines were those recommended by the Radial Velocity Commission of the International Astronomical Union.[1]

Spectrograms of seven brighter class B stars, whose radial velocities previously had

* *Contributions from the Lick Observatory, University of California*, Ser. II, No. 6.

[1] *Trans. I.A.U.*, **4**, 187, 1932.

been well determined at Mount Hamilton and elsewhere, were taken with the instruments used for the present program. The velocities given by the measures of 84 spectrograms by each observer, when compared with the values for these stars given in *A General Catalogue of the Radial Velocities of Stars, Nebulae and Clusters*,[2] yielded the following mean differences: Lick − Neubauer = +0.8 km/sec; Lick − Miss Roosen Raad = +0.4 km/sec. These differences have been applied to the measures by the respective observers in order to reduce all radial velocities to the Lick system. A comparison of the recent values for 19 stars whose velocities appear to be constant and which have also been measured at Victoria give the mean difference: Lick − Victoria = +0.04 km/sec. Since all available evidence indicates that the Victoria velocities are on the Lick system, this would appear to add further evidence that the radial velocities determined on the present program and entered in column 9 of Table 2 at the end of this article, also conform to the Lick system. The probable error of a radial velocity determination based upon an average of 6 plates per star is approximately ±2 km/sec, and for a single plate about ±5 km/sec.

The region of the K line is generally underexposed on most spectrograms that received normal exposure in the region λλ 4000–4600. For many of the stars, however, one or more spectrograms were given sufficient exposure to obtain the K line in measurable strength; and the author's values of the radial velocity derived from this, which in spectra of this type may be regarded as interstellar, are entered in column 11 of Table 2, followed by the number of spectrograms (in parenthesis) on which the line was measured.

The spectrograms of the 433 stars were utilized for a reclassification of the spectra of these stars on the Victoria system. Three independent estimates of the spectral class of each star were made by the writer by comparing the spectrograms with a standard B-type spectrum under a comparator microscope. The mean of the estimates are entered in column 7 of Table 2.

The class B stars for which the radial velocities are here presented are located in two comparatively limited regions of the sky, one centered at approximately 190° galactic longitude, and the other near 350°. Each of these areas extends about 30° in longitude and lies, for the most part, south of the galactic plane. A discussion of the galactic rotation based upon this material alone evidently would contribute little of value, and it is therefore deferred until the radial velocities for the fainter B stars now under observation at Victoria and Mount Hamilton are available. It is of interest, however, to compare the present radial velocity data with those computed for these stars on the basis of current values for the solar motion and the galactic rotation.

After excluding from the 393 stars those in galactic latitudes higher than ±30°, those for which the probable error of a velocity determination exceed ±6.0 km/sec, and those known to be spectroscopic binaries there remained 349. Two additional stars were excluded because their observed velocity differed more than 50 km/sec from that computed for the combined solar motion and galactic rotation. The 347 stars were then arranged in nine groups, the width of a group being taken as approximately 10° of longitude. Data relating to the nine groups are entered in Table 1, the first six columns of which contain, in order, the group identification, the number of stars in the group, galactic longitude, galactic latitude, the mean magnitude, and the mean radial velocity of the stars in the group.

The velocity due to the sun's motion and galactic rotation was computed from the well-known relation

$$V_c = V_0 \cos D + A\bar{r} \sin 2(l - l_0) \cos^2 b ,$$

in which the solar velocity V_0 was taken as 20 km/sec toward the apex $\alpha = 271°$; $\delta = +28°$; A is taken as equal to 0.015 km/sec per parsec; and l_0 as 325°. The mean distance $\bar{r}$ of the stars in a group was derived on the basis of Wilson's[3] absolute magnitudes for the class B stars and was computed by Trumpler's[4] method, in which allowance

[2] *Pub. Lick Obs.*, **18**, 1932. [3] *Ap. J.*, **94**, 12, 1941. [4] *Ap. J.*, **91**, 186, 1940.

is made for a galactic absorption of 0.7 mag. per kiloparsec. The component of the solar velocity $V_0 \cos D$ is given in column 7 and that of the galactic rotation in column 8 of Table 1, while the residual difference between the mean observed radial velocity of a group and the corresponding computed velocity V_c is entered in the final column. Introduction of a K term in the above expression for V_c, having a value of -5.1, would reduce the sum of the weighted residuals for the nine groups to zero. This value of K, although of the same sign, is larger than that found by Trumpler[5] and by Seyfert and Popper[6] for the fainter stars of class B. It will be noticed, however, that the residuals for the last five groups (the Ophiuchus-Serpens-Scutum region) indicate a smaller value of K (-2.3 km/sec) or one of the order obtained by other observers. There is thus, per-

TABLE 1

COMPARISON OF OBSERVED AND COMPUTED VELOCITIES

Group	Stars	l	b	Observed		Computed		(O−C)
				Mag.	Vel.	(V_0 Cos D	$A\bar{r}$ sin 2 (l−325°)	
1.....	11	175°.7	−15°.0	8.15	+17.6	+18.1	+ 7.0	− 7.5
2.....	31	185.1	− 5.8	8.35	+18.7	+18.6	+10.4	−10.3
3.....	47	194.6	− 2.6	7.83	+17.2	+18.9	+ 8.7	−10.4
4.....	48	203.5	+ .15	8.16	+19.0	+18.6	+ 8.5	− 8.1
5.....	3	321.3	+14.3	7.70	−15.3	−10.6	− 1.0	− 3.7
6.....	61	337.2	− 0.6	8.53	− 7.9	−13.2	+ 4.9	+ 0.4
7.....	107	343.5	− 3.2	8.97	−10.1	−14.4	+ 8.3	− 4.0
8.....	24	354.1	− 4.3	8.68	−10.2	−16.1	+10.0	− 4.1
9.....	15	365.6	− 3.5	8.11	− 6.7	−17.6	+ 8.6	+ 2.3

haps, some evidence that the large negative residuals given by the first four groups may be due to the presence of a drift motion of the stars in these groups, which lie in the Orion-Canis Major region.

It is with sincere appreciation that the author acknowledges his indebtedness to Miss Doris Roosen Raad, who measured nearly half of the spectrograms taken on the present program and who rendered valuable assistance in the reduction of the observations.

The data contained in Table 2 are the following:

Col.

1. Number of star in the *Henry Draper Catalogue*
2– 3. Right ascension and declination for the epoch 1900.0
4– 5. Galactic longitude and latitude for the epoch 1900.0
6. Visual magnitude from the *Henry Draper Catalogue*
7. Spectral class on the Victoria system
8. Number of plates used for radial velocity determination. When followed by the letters "a," "b," the plates were taken with both dispersions of 75 A/mm and 150 A/mm. If no letter follows, the 75 A/mm was used

9–10. Radial velocity and its probable error

11. Radial velocity derived from the K line, and in parenthesis the number of plates on which it was measured
12. Remarks: Velocities previously published by Lick are designated by "L"; "V" indicates Victoria; "W," Mount Wilson; "A," Allegheny. The letter "M" refers to Merrill's *Catalogue of Bright Line Stars of Classes B and A*. Variable radial velocity is indicated by "var" and, when doubtful, by "var?" The letter "R" indicates that there is a note at the end of the table

[5] *Ibid.*

[6] *Ap. J.*, **93**, 461, 1941.

TABLE 2

RADIAL VELOCITIES OF 433 CLASS B STARS

HD	α (1900)	δ (1900)	l	b	Mag.	Spec.	Number of Plates	Vel.	P.E.	K Vel.	Remarks	
(1)	(2)	(3	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
886	0h 8m1	+14° 38′	79°	−47°	2.87	B2ss	36a, b	+ 4.6	± 0.6	.....	L + 5.0	R
955	8.8	−18 06	52	−78	7.25	B5n	8	−33.6	1.6	.....		
20340	3 11.2	−17 12	171	−54	7.82	B3n	82	−24.7	1.4	.....	var	R
21996	27.6	−21 35	180	−52	8.8	B4s	9	+28.1	2.4	.....		
23338	39.3	+24 10	134	−22	4.37	B8	11	+ 6.5	0.9	.....	L + 5.4	R
24131	45.5	+34 03	128	−14	5.73	B2	5	+16.8	1.0	.....	V +18.8	
24431	48.1	+52 21	117	0	6.70	O8k	8	−11.2	1.8	.....	V − 8.6	
25539	58.3	+32 18	132	−14	6.70	B3k	6	+30.1	1.8	+ 6 (3)	V +29.6	
25631	59.0	−20 25	182	−44	6.39	B5n	6	+19.7	4.9	.....		
25638	59.1	+62 04	111	+ 8	7.04	B0nk	6	var.	.....	.....	V SB	R
25639	59.1	+62 04	111	+ 8	7.07	B0nk	35	−18	7	.....	V SB	R
28446	4 24.1	+53 42	120	+ 5	6.61	B0sk	10	− 1.6	1.2	+ 3 (3)	V − 0.7	
30614	44.1	+66 10	111	+15	4.38	O9sek	6	+ 3.3	1.3	− 4 (3)	V + 7.0	
30836	45.9	+ 5 26	161	−22	3.78	B2s	6	+41.5	0.5	.....	A SB	R
31726	53.1	−14 24	181	−30	5.87	B3s	4	+11.4	1.0	.....		
32612	59.3	−14 31	182	−29	6.35	B3s	4	+15.8	2.4	.....		
33203	5 3.5	+37 21	137	0	6.17	B2k	6	+ 8.4	1.1	+ 6 (5)	V + 8.9	
34078	9.7	+34 12	140	− 1	5.81	O9ssk	6	+60.2	1.9	+ 5 (2)	V +59.0	
34447	12.3	−17 15	186	−27	6.48	B2s	4	+11.9	2.6	.....		
35007	16.5	− 0 31	170	−19	5.65	B3	6	+ 6.8	0.9	.....	V + 7.8	
35468	19.8	+ 6 16	165	−14	1.70	B2s	6	+17.9	1.0	.....	L +18.0	R
36285	25 5	− 7 31	178	−20	6.24	B3	6	+ 9.0	0.9	.....	V +12.0	
36337	25.9	+14 51	158	− 9	6.62	B8s	6	+15.5	1.0	.....	V +18.7	
36629	28.0	− 4 38	176	−18	8.0	B3s	4	+21.2	0.8	.....		
36824	29.3	+ 5 35	166	−13	6.71	B5	6	+11.6	1.2	.....	V +11.0	
36827	29.3	− 2 57	174	−17	7.8	B8n	4	+ 4.6	1.3	.....		
36898	29.8	− 0 11	172	−16	7.9	B5s	4	+10.1	1.4	.....		
36954	30.1	− 0 48	172	−16	8.1	B3n	45	+ 0.9	0.7	.....	Orbit	R
36958	30.1	− 4 48	176	−18	8.0	B3	4	+23.3	2.8	.....		
36959	30.1	− 6 05	177	−18	5.58	B1k	8	+29.7	1.4	+31 (2)	V +27.6	
37000	30.3	− 6 00	177	−18	8.4	B7	36	+18.8	0.9	.....	Orbit	R
37025	30.4	− 6 06	177	−18	8.2	B5s	7	+21.7	3.2	.....		
37115	31.0	− 6 41	177	−18	8.2	B5ne	7	+ 9.0	2.4	.....	W	R
37128	31.0	− 1 16	173	−16	1.75	cB0k	6	+28.0	1.2	+20 (3)	L +25.8	R
37334	32.7	− 5 00	176	−17	7.30	B3	5	+28.4	2.0	.....		
37699	35.4	− 2 30	174	−15	9.1	B4n	4	+14.8	2.2	.....		
37776	35.9	− 1 32	174	−15	8.2	B3s	7	+25.5	2.6	.....		
37903	36.7	− 2 18	174	−15	8.6	B3n	6	+ 5.9	1.5	.....		
37971	37.2	−16 46	188	−21	6.10	B5s	6	+15.5	1.9	.....		
38426	40.6	−21 42	193	−23	6.68	B4s	4	+19.1	0.7	.....		
38622	42.0	+13 52	161	− 6	5.20	B3s	6	+26.9	2.3	.....	V +29.3	
39716	49.2	− 6 46	180	−14	8.6	B5s	4	+16.8	0.9	.....		
41541	6 00.7	+42 41	138	+12	6.88	B5	6	+ 4.9	1.7	.....	V + 4.2	
41756	01.9	− 3 20	178	−10	6.75	B5	5	+21.2	1.3	.....	V +17.6	
41814	02.2	−11 10	186	−14	6.38	B5s	8	+12.9	1.6	.....		
42050	03.5	− 5 19	180	−10	8.5	B3s	6	+13.3	2.4	.....		
42051	03.5	− 6 31	182	−11	8.9	B2n	5	+10.3	1.8	.....		
42204	04.3	− 3 46	179	−10	7.9	B5s	5	+13.1	1.0	.....		
42259	04.6	− 5 03	180	−10	8.35	B5ne	7	var.	.....	.....		R
42261	04.6	− 6 18	182	−11	9.1	B4	4	+10.3	2.0	.....		
42745	07.3	−14 25	189	−14	8.1	B3n	5	+12.4	2.4	.....		
42927	08.4	−17 44	192	−15	6.31	B4n	6	+ 8.4	1.6	.....		
43544	11.7	−16 35	192	−14	5.88	B5n	4	+13.6	1.7	.....		
43777	13.0	− 0 21	177	− 6	8.3	B3nk	4	+20.4	1.8	+ 6 (4)		
44081	14.7	−20 53	196	−15	5.66	B5	6	+30.9	0.8	.....		
44743	18.3	−17 54	194	−13	1.99	B1ss	16	+34.2	0.6	.....	L +34.4	R
45585	23.2	− 6 51	184	− 7	8.9	B5n	6	+ 7.2	1.4	.....		
46064	26.0	−13 05	190	− 9	6.09	B2sk	4	+ 2.3	0.5	+ 6 (3)		
46185	26.8	−12 30	190	− 9	6.76	B3	4	+ 6.9	1.3	.....		
46339	27.7	− 4 22	182	− 5	8.9	B3nk	7	+ 6.1	2.0	− 7 (3)		
46380	27.9	− 7 26	185	− 6	8.4	B5ne	5	+15.3	3.4	.....		R
46428	28.2	−12 00	189	− 8	8.5	B4n	6	+10.7	1.6	.....		
46446	28.3	−20 57	198	−12	7.13	B4	6	− 2.0	3.5	.....		
46519	28.8	− 8 06	186	− 6	9.1	B5n	6	+20.0	2.3	.....		
46738	29.9	− 8 32	186	− 6	8.9	B4	5	+ 8.8	± 6.4	.....	var?	

TABLE 2—*Continued*

HD	α (1900)	δ (1900)	l	b	Mag.	Spec.	Number of Plates	Vel.	P.E.	K Vel.	Remarks	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
47299	6h32m8	− 8° 34′	187°	− 6°	8.5	B5n	4	+22.5	± 4.5	.....		
47300	32.8	− 9 18	187	− 6	8.6	B9	4	+24.9	3.0	.....		
47761	35.1	− 4 36	184	− 3	8.5	B0ek	6	+29.0	5.7	+25 (5)	var	R
48038	36.3	−12 05	190	− 6	6.78	B2k	4	−10.5	2.3	+ 6 (2)		
48282	37.5	−10 24	189	− 5	9.0	B5ne	4	+24.5	5.7	.....		R
48355	37.9	−22 20	200	−11	8.5	B5n	6	+16.6	2.1	.....		
49097	41.5	−13 44	192	− 6	8.9	B4n	5	+33.4	1.5	.....		
49233	42.3	−23 03	201	−10	8.3	B8	5	+19.5	2.0	.....		
49315	42.7	−15 58	194	− 7	7.54	B5	4	+ 8.6	1.1	.....		
49888	45.5	−12 29	192	− 5	7.4	B5se	4	+ 3.0	0.9	.....		R
49977	45.9	−14 00	193	− 5	7.9	B2ne	6	+15.5	2.7	.....	M	R
50091	46.5	−13 07	192	− 5	8.5	B3n	6	+ 5.6	7.1	.....	var	
50118	46.6	−20 48	199	− 8	7.09	B3n	5	+18.3	2.8	.....		
50230	47.2	− 0 33	181	+ 1	8.7	B3k	6	+17.1	1.9	+11 (5)		
50348	47.7	− 3 34	184	0	8.9	B4n	6	− 0.8	1.5	.....		
50463	48.3	−16 06	195	− 6	6.99	B3	6	+16.6	2.0	.....		
50562	48.7	−21 43	200	− 8	8.5	B3nk	5	+25.3	1.0	+ 8 (4)		
50846	49.8	− 1 15	182	+ 2	8.3	B5s	6	+15.8	4.2	.....		
50891	50.0	− 3 34	184	+ 1	9.2	O8k	5	+41.2	2.2	+10 (5)		
51193	51.3	− 3 40	185	+ 1	8.7	B3nek	6	+59.8	1.8	+16 (6)		R
51200	51.3	−21 54	200	− 8	6.81	B4	6	+10.4	4.3	.....	var?	
51452	52.3	− 4 04	185	+ 1	8.5	B3nk	5	+27.2	4.5	+26 (4)		R
51477	52.4	− 8 24	189	− 1	8.3	B5	6	−47.3	5.2	.....	var	
51549	52.6	−20 58	200	− 7	8.1	B5	5	+17.0	2.2	.....		
51756	53.5	− 2 53	184	+ 2	7.7	B3k	5	+25.1	4.4	+30 (4)		
51790	53.6	−21 47	201	− 7	9.2	B9	7	+ 0.7	7.3	.....	var	
51854	53.8	−22 44	202	− 8	9.2	B4n	6	+27.0	1.8	.....		
51898	54.0	−20 23	200	− 7	8.9	B5n	5a, b	+25.1	1.1	.....		
52162	55.0	−12 51	193	− 3	7.9	B3n	6	+21.3	1.6	.....		
52244	55.3	−16 03	196	− 4	9.0	B5e	5	− 1.2	1.2	.....	M	R
52437	56.1	−21 59	201	− 7	6.33	B4n	8	+ 9.0	3.1	.....		
52533	56.5	− 2 59	185	+ 2	7.9	B6	6	+ 5.5	1.4	.....		
52718	57.2	− 3 08	185	+ 2	9.2	B4s	6	+27.3	2.2	.....		
52721	57.2	−11 09	192	− 2	6.57	B3e	8	+21.8	3.7	.....	M	R
52942	58.0	−11 19	192	− 1	8.7	B3nk	11	var	.....	+36 (3)		R
53035	58.4	−11 03	192	− 1	8.1	B4s	6	+19.2	1.4	.....		
53179	59.0	−11 24	192	− 1	9.1	Beq	5	var	.....	.....	M	R
53339	59.6	−11 15	192	− 1	9.1	B5	5a, b	+16.8	2.3	.....		
53340	59.6	−15 11	196	− 3	8.35	B4s	5	+21.6	2.8	.....		
53456	7 00.0	−11 23	192	− 1	7.8	B3	6	+18.0	1.9	.....		
53667	00.8	− 8 34	190	+ 1	7.8	O8k	6	+36.2	5.2	.....	var	
53754	01.1	− 8 39	190	+ 1	8.4	B2k	6	+41.5	2.0	+16 (4)		
53756	01.1	−12 40	194	− 1	7.20	B4n	7	+19.1	15.8	.....	var	
53857A	01.5	−12 48	194	− 1	8.5	B5n	9	− 0.4	2.6	.....		R
53857B	01.5	−12 48	194	− 1	8.7	B4s	5	+27.1	4.2	.....		R
53948	01.9	−12 33	194	− 1	10.1	B9	6b	+15.5	1.9	.....		
53975	02.0	−12 14	193	− 1	6.40	B5	6	+33.7	2.5	.....		
54024	02.2	− 7 35	189	+ 1	8.9	B5s	5	+35.8	2.6	.....		
54025	02.2	−11 10	192	0	8.4	B4	6	+17.4	0.7	.....		
54081	02.4	− 5 08	187	+ 2	10.0	B4	6a, b	+38.4	1.1	.....		
54104	02.5	− 9 26	191	+ 1	8.0	B4n	6	+19.1	1.4	.....		
54306	03.2	−11 46	193	0	9.2	B5s	6	+18.7	0.9	.....		
54575	04.2	−15 46	197	− 2	8.3	B5s	6	−27.5	10.1	.....	var	R
54662	04.6	−10 11	192	+ 1	6.20	O7k	6	+56.7	0.6	+34 (6)	V +63.0	
54764	05.0	−16 04	197	− 2	6.03	B3	6	+ 6.4	0.8	.....		
54879	05.5	−11 39	193	0	7.9	B3k	7	+15.6	1.4	+ 8 (4)		
54911	05.6	−15 31	197	− 2	7.03	B4s	6	+15.9	0.6	.....		
54935	05.7	−19 25	200	− 4	7.5	B5	5	+20.2	1.4	.....		
55135	06.6	−10 16	192	+ 1	7.16	B5e	5	+16.5	3.0	.....	V +11.0 M	R
55394	07.6	−14 38	196	− 1	9.0	B5n(e	6	− 8.6	2.2	.....		R
55442	07.8	−12 00	194	0	9.3	B4	6b	+22.0	2.3	.....		
55538	08.2	−15 19	197	− 1	8.1	B4n	6	+17.3	1.3	.....		
55692	08.8	−20 24	201	− 3	8.1	B3n	6	+22.6	1.6	.....		
55753	09.1	− 7 08	190	+ 3	9.3	B5s	6a, b	+29.0	2.9	.....		
55856	09.6	−22 44	203	− 4	6.24	B3s	7	+17.4	± 0.6	.....		

TABLE 2—*Continued*

HD	α (1900)	δ (1900)	l	b	Mag.	Spec.	Number of Plates	Vel.	P.E.	K Vel.	Remarks	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
55879	7h09m7	−10°08′	192°	+ 2°	5.99	O9sk	6	+33.7	± 1.2	+33 (4)	V +31.9	
56013	10.2	−19 48	201	− 3	7.29	B2n	6	+20.0	1.0	.....		
56310	11.4	−16 03	198	− 1	6.79	B4n	48	+24.4	0.5	.....	Orbit	R
56727	13.1	−18 33	200	− 2	8.9	B5n	6	+23.9	3.0	.....		
56827	13.5	−11 47	194	+ 2	10.0	B3s	6b	+23.1	3.0	.....		
56847	13.6	−15 27	198	0	8.7	B2n	6	+21.4	1.9	.....		
56952	14.0	−17 01	199	− 1	9.1	B4n	6a, b	+ 8.4	1.9	.....		
57236	15.2	−21 49	203	− 3	8.7	B3n	6	+19.4	2.5	.....		
57370	15.8	−21 42	203	− 3	9.1	B5n	6	+25.5	3.5	.....		R
57573	16.7	−22 40	204	− 3	6.45	B4n	6	+10.5	2.2	.....		
57907	18.2	−17 26	200	0	8.3	B5s	6	+28.6	2.2	.....		
57910	18.2	−22 50	204	− 3	9.2	B5n	6b	+ 9.5	2.1	.....		
58131	19.1	−20 02	202	− 1	7.33	B2nk	6	+32.2	1.2	+30 (4)		
58416	20.4	−20 31	203	− 1	9.5	B2n	6a, b	+16.3	2.8	.....		
58465	20.6	−20 49	203	− 1	8.7	B4	6	+27.1	3.0	.....		
58509	20.8	−20 49	203	− 1	8.5	B4n	6	+23.8	2.7	.....		
58510	20.8	−20 59	203	− 1	6.73	B2nk	7	+20.2	0.6	+19 (2)		
58529	20.9	−10 34	194	+ 4	9.0	B8	6	− 3.8	1.5	.....		
58973	22.8	− 2 52	188	+ 8	8.4	B5s	7	− 3.1	0.8	.....		
59094	23.3	−15 53	199	+ 2	9.0	B3nn	5	+14.7	1.3	.....		
59497	25.1	−21 38	204	− 1	8.4	B3ne	6	+14.6	3.3	.....	M	R
59543	25.3	−13 46	198	+ 3	6.94	B4n	57	+ 4.7	0.5	.....	Orbit	R
59773	26.4	−21 35	204	0	8.1	B4	6	+20.1	2.2	.....		
59813	26.6	−18 43	202	+ 1	9.1	B3n(k)	6	+16.0	7.4	.....	var	
59910	27.0	−21 01	204	0	9.1	B9	6a, b	+30.5	3.1	.....		
59934	27.1	−16 59	200	+ 2	7.8	B4s	6	+15.5	2.2	.....		
60260	28.5	−11 24	196	+ 5	8.9	B4ne	5	+19.2	5.0	.....	var?	R
60235	28.8	−14 07	198	+ 4	6.24	B5	7	+21.4	2.0	.....		
60553	29.9	−19 55	203	+ 1	6.81	B2s	10	+28.2	1.3	.....		R
60855	31.4	−14 16	199	+ 4	5.57	B5n(e)	6	+21.1	1.2	.....		
60859	31.4	−19 34	203	+ 2	9.1	B4n	6a, b	+24.6	2.1	.....		
60873	31.5	−10 03	195	+ 6	8.31	B5n	6	+ 4.2	13.6	.....	var	
60993	32.0	−12 50	197	+ 5	9.1	B3n	6a, b	+22.9	2.9	.....		
61022	32.1	−20 00	204	+ 2	9.6	B4s	6	+28.3	4.7	.....		
61068	32.3	−19 29	203	+ 2	5.66	B3s	6	+21.7	3.4	.....		
61207	33.0	−15 28	200	+ 4	7.9	B5	7	+14.7	3.1	.....		
61347	33.7	−13 38	198	+ 5	8.3	B3	7	+38.7	5.3	.....	var	
61407	34.0	−22 01	206	+ 1	9.0	B7	7a, b	+10.4	2.2	.....		
62053	37.0	−18 56	203	+ 3	9.1	B5	6a, b	+14.4	1.6	.....		
62391	38.6	−20 56	205	+ 2	9.4	B4n	7b	+12.5	2.3	.....		
62532	39.3	−17 42	203	+ 4	8.6	B3ne	5	+30.1	5.2	.....		R
62589	39.6	−16 41	202	+ 5	8.1	B5n	5	+16.2	1.8	.....		R
62678	40.1	−21 15	206	+ 2	10.5	B4ne	8	+30.1	1.2	.....		R
62729	40.3	−15 52	201	+ 5	8.0	B5(e)	7	+14.8	2.3	.....		
63271	42.9	−22 17	207	+ 2	5.84	B2sk	5	+ 7.4	3.2	+15 (4)		
64298	48.1	−21 45	207	+ 4	8.7	B3(e)	6	+ 5.3	2.6	.....		R
64418	48.7	−22 07	208	+ 4	9.6	B4	7b	+16.0	1.3	.....		
65307	53.0	− 8 34	196	+12	9.1	B4s	11a, b	+23.5	17.3	.....	var	R
66396	58.2	−21 55	208	+ 6	9.0	B5	7	+21.2	2.0	.....		
66594	59.2	− 4 32	194	+15	7.38	B5s	6	+10.2	1.0	.....		
66738	59.8	−12 51	201	+11	7.5	B3k	9	+12.8	3.6	+ 3 (7)		
66834	8 00.2	−19 26	207	+ 7	6.06	B4s	10	+13.8	1.5	.....		
67072	01.2	−16 04	204	+ 9	9.2	B5	6a, b	+29.7	2.3	.....		
67303	02.2	−17 33	205	+ 9	9.2	B5s	8a, b	+10.7	2.1	.....		
68444	07.3	−14 22	203	+12	9.2	B4n	7a, b	+15.2	2.9	.....		
68468	07.4	−13 52	203	+12	8.5	B4sek	7	+14.8	3.8	+11 (6)	W +12	R
69562	12.4	−21 34	210	+ 9	6.70	B4s	10	+11.8	1.7	.....	var?	R
71518	22.8	−14 36	206	+15	6.55	B5ss	7	+12.0	5.3	.....		
76510	51.5	−13 31	209	+21	8.2	B4n	6	+21.6	2.0	.....		R
89884	10 17.2	−17 32	228	+33	6.99	B5n(e)	6	+22.2	2.8	.....		
119608	13 39.1	−17 26	289	+42	7.32	B1sk	5	+19.9	0.7	+ 0 (4)		
123884	14 05.1	−17 31	297	+40	9.3	B4s	9	+ 6.1	1.6	.....		
127493	26.6	−22 13	300	+34	10.0	O9	6	+13.2	2.0	.....		
135485	15 10.2	−14 19	316	+34	8.3	B3sk	8	−15.8	2.2	−10 (5)		
140543	39.1	−21 30	315	+24	8.5	B1nk	6	− 5.9	± 4.9	− 9 (4)		

TABLE 2—*Continued*

HD (1)	α (1900) (2)	δ (1900) (3)	l (4)	b (5)	Mag. (6)	Spec. (7)	Number of Plates (8)	Vel. (9)	P.E. (10)	K Vel. (11)	Remarks (12)	
147888	16h19m4	−23°14′	322°	+16°	6.56	B4	7	− 9.5	± 2.0	.....		
149363	29.1	− 5 56	338	+25	8.0	Bonk	7	+96.6	4.3	+26 (4)		R
149382	29.2	− 3 48	340	+26	9.0	B5n	7	+ 3.3	4.9	.....	var?	
152516	48.7	−21 43	327	+12	8.08	B3s	9	−30.4	2.1	.....		
156779	17 14.4	−18 43	333	+ 9	9.0	B4s	7	−15.4	1.2	.....		
157857	20.7	−10 55	341	+12	7.43	O7	5	+59.5	1.0	.....	V +57.6	
158319	23.5	−16 31	336	+ 8	8.7	B5ne	6	−14.2	1.1	.....	M	R
158659	25.4	−11 06	341	+11	10.3	B4s	6a, b	+38.6	19.1	.....	var	
159864	31.8	−17 46	336	+ 6	8.8	B1nk	6	+ 6.9	1.2	−10 (4)		
160186	33.4	−18 21	336	+ 5	8.8	B4	6	+ 5.8	1.3	.....		
160233	33.7	+ 4 24	356	+17	8.6	B5	5	−24.3	1.9	.....		
160762	36.6	+46 04	39	+30	3.79	B3s	9a, b	−18.6	0.5	.....	L −18.1	R
160886	37.3	−18 16	336	+ 5	10.0	B8	6b	−19.5	4.3	.....		
161306	39.7	− 9 46	344	+ 8	8.31	B0ne	6	−21.6	7.2	.....	M var?	
161961	43.4	− 2 09	351	+11	8.2	B1sk	6	−13.0	1.1	− 8 (6)	W −3E	R
162365	45.6	+15 32	8	+19	7.7	B4s	6	−22.1	2.9	.....		
163535	51.5	−18 03	338	+ 2	9.2	B8	5b	−14.8	4.1	.....		
163800	52.9	−22 30	335	− 1	6.92	B0	10	+ 5.2	4.2	.....	var	
163892	53.4	−22 27	335	− 1	7.14	B2nk	8	−14.5	2.4	−15 (4)		
164002	53.9	−22 33	335	− 1	7.15	B2k	10	−17.1	3.7	−25 (9)	var	
164103	54.5	−14 47	342	+ 3	8.04	B5	8	−30.6	4.9	.....	var	
164188	54.9	−15 48	341	+ 2	9.0	B3k	7	+ 6.3	1.9	−12 (7)		
164359	55.6	−22 07	335	− 1	8.2	B1nk	7	−14.2	2.2	−14 (4)		
164438	56.0	−19 06	338	0	7.28	B1nk	8	−26.9	4.9	−24 (4)		
164492	56.3	−23 01	335	− 2	6.91	O9	5	.....	.....	.....		
164536	56.5	−24 15	334	− 2	6.87	B4n	5	−11.1	3.2	.....		
164581	56.7	−20 44	337	− 1	6.85	B4	8	− 5.5	4.2	.....		
164637	57.0	−22 43	335	− 2	6.57	B0sk	6	−10.4	1.6	−11 (5)		
164700	57.3	−17 24	340	+ 1	8.0	B4s	6	+ 2.0	4.0	.....	var?	
164703	57.3	−22 18	335	− 2	9.8	B5n	6a, b	− 9.7	5.8	.....	var	
164704	57.3	−22 53	335	− 2	7.65	B4	7	− 4.9	3.3	.....	var?	
164717	57.4	−22 36	335	− 2	8.6	B4n	6	−19.4	1.5	.....		
164738	57.5	−17 36	340	+ 1	7.10	B5n	5	+ 5.9	3.8	.....		
164833	57.9	−22 50	335	− 2	6.86	B0	5	−22.6	2.6	.....		
164844	58.0	−22 34	335	− 2	8.9	B5	6	−16.9	0.9	.....		
164863	58.1	−22 30	335	− 2	7.8	B7	6	+12.2	8.9	.....	var	
164883	58.2	−22 30	335	− 2	7.8	B0nk	5	−11.2	1.6	−16 (4)		
164992	58.7	−22 27	336	− 2	10.7	B4	6b	−25.2	2.7	.....		
165049	59.0	−15 22	342	+ 2	8.07	B1sk	5	−17.1	1.2	−10 (1)		
165285	18 00.1	−19 58	338	− 1	8.73	B2ne	6	−11.4	2.5	.....	M	
165287	00.1	−22 07	336	− 2	8.9	B5n	6	+ 4.7	6.4	.....	var	
165288	00.1	−22 28	336	− 2	9.9	B4s	6a, b	− 6.6	2.5	.....		
165516	01.2	−21 27	337	− 2	6.22	B2sk	8	−13.9	1.0	−21 (6)	W − 5.8	
165612	01.7	−22 54	335	− 3	8.9	B3n	5	−15.9	4.4	.....		
165689	02.1	−22 17	336	− 2	8.6	B5	5	−11.6	2.4	.....		
165765	02.5	−22 44	336	− 3	9.9	B4	6a, b	−19.8	3.2	.....		
165808	02.7	−16 26	341	0	8.1	B5	5	−15.5	2.5	.....		
165812	02.7	−22 10	336	− 3	7.89	B2sk	5	−24.4	3.3	−11 (3)	var	
165857	02.9	−22 11	336	− 3	9.4	B4	6a, b	−34.4	6.5	.....	var	
166054	03.8	−22 04	336	− 3	9.9	B3	5b	−20.5	3.6	.....		
166125	04.1	−14 12	343–	+ 1–	9.1	B3	6a, b	−19.3	2.2	.....		
166182	04.4	+20 48	15	+17	4.32	B2sk	18a, b	−14.6	1.2	−21 (8)	L −13.3	R
166188	04.4	−18 13	340	− 1	9.4	B2e(k)	6b	−23.4	2.4	.....	M	R
166287	04.8	−16 50	341	0	7.6	B3k	6	−17.0	2.1	−17 (6)		
166291	04.8	−19 12	339	− 2	9.1	B4	6a, b	−22.8	1.5	.....		
166304	04.9	−16 44	341	0	9.7	B4	6b	−23.0	3.2	.....		
166418	05.4	−16 44	341	0	8.7	B1sk	6	+ 6.4	1.6	−20 (5)		
166443	05.5	−20 44	338	− 2	8.7	B0e	6	− 1.1	2.1	.....		R
166539	06.0	−15 37	342	0	8.9	B1nk	6	− 0.5	2.5	− 8 (5)		
166540	06.0	−16 55	341	− 1	8.3	B1sk	5	− 1.6	1.6	−16 (5)		
166546	06.0	−20 27	338	− 2	7.17	B1k	6	+ 1.3	0.7	−10 (6)		
166566	06.1	−15 42	342	0	8.1	B2sek	6	−11.0	4.3	− 9 (6)	M	R
166568	06.1	−18 45	340	− 2	10.3	B2(e)k	6b	−18.9	2.4	−25 (6)		R
166628	06.4	−19 28	339	− 2	7.14	B3sk	6	+ 3.1	2.0	−11 (6)		
166666	06.6	−15 36	342	0	9.4	B3(e)	6b	− 3.7	± 6.0	.....	var? M	R

TABLE 2—*Continued*

HD	α (1900)	δ (1900)	l	b	Mag.	Spec.	Number of Plates	Vel.	P.E.	K Vel.	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
166689	18h06m7	−16°24′	342°	− 1°	7.34	B1sk	5	− 4.6	± 1.7	−10 (5)	
166716	06.8	−15 25	343	0	7.95	B1sk	6	− 6.1	2.6	− 7 (6)	
166734	06.9	−10 46	347	+ 2	8.3	B1n	5	−10.6	3.1	.....	
166787	07.1	−19 47	339	− 2	8.9	B2k	6	− 7.6	2.5	−10 (4)	
166803	07.2	−15 13	343	0	8.1	B2nk	6	− 3.2	1.5	−12 (6)	
166826	07.3	−20 26	338	− 3	9.9	B5	5a, b	−12.0	4.1	.....	
166852	07.4	−22 45	336	− 4	8.50	B1	5	−17.4	2.1	.....	
166920	07.7	−17 19	341	− 1	11.0	B5n	5b	−22.1	2.5	.....	
166934	07.8	−18 51	340	− 2	8.7	B9	6	+15.5	7.1	.....	var R
166963	07.9	−16 36	342	− 1	10.1	B4n	5b	−19.8	2.4	.....	
166964	07.9	−17 10	341	− 1	9.4	B5	5b	−26.5	4.0	.....	
166965	07.9	−19 02	340	− 2	9.7	B3n	6a, b	−13.0	5.7	.....	
166999	08.1	−19 09	339	− 2	10.1	B5	6b	− 6.2	5.8	.....	
167000	08.1	−20 41	338	− 3	9.7	B5	6b	−20.1	3.2	.....	
167088	08.6	−19 06	340	− 2	9.1	B3k	6	− 9.6	2.6	−23 (5)	
167090	08.6	−20 30	338	− 3	10.3	B5s	5a, b	−10.5	3.0	.....	
167200	09.0	−22 28	337	− 4	9.4	B4n	6a, b	− 8.4	1.0	.....	
167224	09.1	−18 59	340	− 2	8.9	B4	6	−12.4	1.4	.....	
167263	09.3	−20 25	338	− 3	6.02	B1nk	6	−10.4	1.4	− 6 (5)	
167287	09.4	−19 01	340	− 2	8.3	B0k	7	+ 0.1	7.7	+ 1 (6)	var R
											R
167311	09.5	−12 32	346	+ 1	8.3	B2n(k)	6	− 4.1	2.8	− 2 (5)	
167313	09.5	−15 01	343	− 1	10.7	B5	6a, b	−25.7	2.7	.....	
167330	09.6	−12 34	345	+ 1	8.1	B0n	8	−35.5	8.4	.....	var R
167332	09.6	−16 00	342	− 1	10.1	B8	6a, b	−24.2	1.4	.....	
167336	09.8	−18 24	340	− 2	9.4	B5	6a, b	− 2.9	4.2	.....	
167372	09.8	−14 37	344	0	11.0	B4s	6b	−23.9	1.7	.....	
167397	09.9	−17 00	342	− 2	9.2	B0k	6a, b	+ 3.6	2.4	− 4 (4)	
167409	10.0	−14 46	344	− 1	10.1	B4s	6a, b	−19.7	1.5	.....	
167411	10.0	−18 17	340	− 2	8.6	B3k	6	− 8.1	1.5	− 8 (4)	
167412	10.0	−18 29	340	− 2	9.4	B5	6b	−17.9	2.9	.....	
167432	10.1	−17 09	341	− 2	10.6	B8s	6b	−33.7	1.1	.....	
167436	10.1	−20 03	339	− 3	9.9	B4	8	−28.4	2.3	.....	
167451	10.2	−13 36	344	0	7.9	B4	6	−15.4	4.5	.....	var? R
167478	10.3	−18 28	340	− 2	10.3	B5	6b	−26.4	2.3	.....	
167479	10.3	−18 49	340	− 2	8.8	B3k	6	−10.6	1.8	− 5 (6)	
167497	10.4	−14 20	344	0	9.4	B4n	6a, b	−22.4	1.8	.....	V +13.5 SB
167771	11.6	−18 30	340	− 3	6.37	O8k	2	−11.	.....	.....	
167785	11.7	+10 48	6	+11	7.9	B5s	6	−18.8	2.5	.....	
167815	11.8	−19 42	339	− 3	7.59	B2nk	9	− 6.9	1.3	−25 (8)	
167838	11.9	−15 28	343	− 1	6.64	B0k	9	− 6.6	1.1	−11 (9)	
167863	12.0	−18 51	340	− 3	6.57	B8s	6	−14.7	0.5	.....	
167902	12.2	−18 00	341	− 2	9.7	B5	6b	−19.0	2.9	.....	
167971	12.5	−12 17	346	0	7.34	B1nk	7	− 4.1	4.8	−19 (3)	
167999	12.6	−16 41	342	− 2	9.7	B4	6b	− 7.3	1.9	.....	
168021	12.7	−18 39	340	− 3	6.38	B0sk	9	− 8.2	2.8	−21 (6)	
168078	12.9	−17 06	342	− 2	10.6	B5	6b	−36.5	4.8	.....	var?
168080	12.9	−18 12	341	− 3	8.3	B3nk	7	+ 4.8	3.9	− 5 (7)	var?
168112	13.1	−12 08	346	0	8.7	B4	7	− 8.3	4.3	.....	
168138	13.2	−19 29	340	− 3	9.4	B4n	9a, b	− 7.9	1.7	.....	
168162	13.3	−15 31	343	− 2	9.7	B2(k)	6b	−33.1	1.9	.....	
168163	13.3	−16 20	342	− 2	9.1	B5q	6	−15.4	2.8	.....	var R
168183	13.4	−14 02	345	− 1	8.3	B0nk	6	− 4.0	13.8	.....	
168207	13.5	−14 12	344	− 1	10.1	B0n	6b	− 5.0	4.3	.....	var?
168230	13.6	−18 54	340	− 3	10.6	B3s	6b	− 2.2	7.3	.....	
168279	13.8	−18 11	341	− 3	10.6	B8	6b	−26.5	3.4	.....	
168302	13.9	−16 03	343	− 2	9.9	B5n	8	−41.1	1.9	.....	
168352	14.1	−17 07	342	− 2	9.4	B2nk	6	−27.8	1.8	−30 (3)	
168368	14.2	−17 06	342	− 2	10.1	B3	6b	− 1.3	3.5	.....	
168418	14.4	−17 02	342	− 2	9.7	B3	6b	−20.5	5.2	.....	
168444	14.6	−14 53	344	− 2	8.86	B0k	6	−16.3	2.5	−23 (4)	
168449	14.6	−18 31	341	− 3	11.0	B5n	6b	−16.3	2.5	.....	
168489	14.8	−17 48	341	− 3	8.9	B1k	6	− 8.0	1.7	−31 (5)	
168552	15.2	−17 11	342	− 3	8.7	B3sk	6	− 7.4	1.4	−21 (6)	
168571	15.3	−17 26	342	− 3	8.3	B2k	7	− 4.8	0.7	− 9 (6)	
168675	15.9	−17 57	341	− 3	9.4	B4	6a, b	− 5.7	± 5.2	.....	var?

TABLE 2—*Continued*

HD (1)	α (1900) (2)	δ (1900) (3)	l (4)	b (5)	Mag. (6)	Spec. (7)	Number of Plates (8)	Vel. (9)	P.E. (10)	K Vel. (11)	Remarks (12)	
168726	18h16m1	−16°39′	342°	− 3°	9.7	B7	6b	− 7.0	± 3.7	.....		
168748	16.2	−17 09	342	− 3	10.6	B5s	6b	−31.6	2.6	.....		
168765	16.3	−17 28	342	− 3	9.9	B4	8	−17.7	2.0	.....		
168917	17.1	−14 25	345	− 2	8.6	B5s	6	−15.7	2.1	.....		
169014	17.5	−16 46	343	− 3	9.4	B5s	6a, b	− 7.6	2.9	.....		
169034.....	17.6	−13 39	345	− 2	8.3	B3	6	− 6.9	3.6	.....		
169271.....	18.8	−18 20	341	− 4	9.4	B4	6a, b	−10.6	5.5	.....		
169419.....	19.4	−17 35	342	− 4	9.4	B0n	6	+ 2.6	1.2	.....		
169454.....	19.6	−14 02	345	− 2	6.84	O8	10	−25.2	1.5	.....		
169673.....	20.7	−15 41	344	− 3	7.17	B1nk	8	−16.8	1.4	−16 (7)		
169695.....	20.8	−16 43	343	− 4	10.6	B8	6b	−25.7	2.0	.....		
169704.....	20.9	−21 35	339	− 6	9.9	B4	6a, b	−16.1	2.1	.....		
169727.....	21.0	−13 43	346	− 2	9.4	B0n	6a, b	−13.1	3.8	.....		
169753.....	21.1	− 9 15	350	0	var	B2k	21	−29.0	6.0	.....	var	R
169754.....	21.1	−11 25	348	− 1	8.1	B1nk	7	+35.	16.	.....	var	R
169755.....	21.1	−14 34	345	− 3	9.7	B3n(k)	6b	− 0.8	2.5	.....		R
169827.....	21.4	−17 21	342	− 4	9.1	B6	8	−11.1	2.2	.....		
170061.....	22.4	−14 47	345	− 3	10.6	B0ne	7b	+ 9.4	2.7	.....	M	R
170097.....	22.6	−16 46	343	− 4	8.5	B0n	10	+13.9	6.1	.....	var	
170159.....	22.9	−13 04	346	− 2	8.7	B2n	6	− 8.8	0.9	.....		
170177.....	23.0	−13 34	346	− 3	9.4	B1k	6	+12.6	7.4	.....	var?	
170452.....	24.4	−13 01	347	− 3	8.5	B5	7	−13.9	2.9	.....	var	R
170453.....	24.4	−14 17	346	− 3	9.9	B2nk	6a, b	+ 5.0	2.8	− 2 (4)		
170581.....	25.1	−13 43	346	− 3	9.4	B3k	6a, b	+18.6	2.9	+15 (6)		
170604.....	25.2	−16 39	344	− 5	8.7	B1k	6	− 5.0	3.6	+ 3 (5)		
170700.....	25.7	−14 11	346	− 4	9.1	B0k	6	+ 0.5	3.1	− 1 (4)		
170714.....	25.8	− 5 51	353	0	7.31	B5n	9	−16.7	3.1	.....	V −24.3	
170716.....	25.8	−12 24	347	− 3	8.9	B1	6	+ 1.9	3.5	.....		
170783.....	26.1	+ 4 34	2	+ 5	7.70	B5	5	−18.6	2.9	.....		
170796.....	26.2	−15 44	344	− 4	9.7	B5	6a, b	+ 2.2	5.7	.....	var?	
170938.....	26.9	−15 46	344	− 4	8.7	B0k	6	+26.9	5.1	− 9 (3)	var?	
171012.....	27.3	−18 26	342	− 6	6.98	B0sek	8	−17.5	1.8	− 3 (6)	var M	R
171054.....	27.5	−13 59	346	− 4	9.4	B4s(k)	6a, b	+ 2.5	2.9	.....		
171198.....	28.3	−12 20	348	− 3	9.2	B0nk	9	+54.	30.	.....	var	R
171293.....	28.9	−14 29	346	− 4	10.1	B4	7b	−25.6	0.9	.....		
171348.....	29.3	−22 10	339	− 8	8.1	B3e	7	− 8.7	4.8	.....	M	R
171392.....	29.5	−14 23	346	− 5	10.3	B5	6	− 3.2	3.5	.....		
171432	29.7	−18 38	342	− 6	8.1	B3k	6	+12.8	0.7	− 9 (6)		
171469.....	29.9	−15 48	345	− 5	9.4	B4n	6a, b	+ 2.8	3.6	.....		
171491.....	30.0	− 0 02	359	+ 2	8.28	B5	6	−19.5	3.5	.....		
171589.....	30.6	−14 12	346	− 5	8.8	B3nk	6	+14.7	3.4	+ 7 (6)		
171611.....	30.7	−20 24	341	− 8	7.37	B4	6	−22.8	1.9	.....		
172028.....	32.8	− 0 29	359	+ 1	8.1	B3k	6	−12.8	1.6	−18 (3)		
172175.....	33.6	− 7 57	352	− 2	9.4	B0n(e)	8a, b	− 8.0	8.4	.....	var	R
172176.....	33.6	−14 47	346	− 6	9.9	B5	7b	−36.5	3.8	.....		
172252.....	34.1	−11 58	349	− 4	8.7	B0n	6	−10.8	3.5	.....		
172256.....	34.1	−22 45	339	− 9	8.9	B5(e)	6	+ 3.3	6.0	.....	var?	R
172275.....	34.2	− 7 27	353	− 2	9.4	B4	6a, b	+22.7	4.1	.....		
172293.....	34.3	−15 24	346	− 6	10.3	B5	6b	−23.7	1.6	.....		
172367.....	34.7	− 7 20	353	− 2	9.7	B5n	7	−10.6	2.9	.....		R
172427.....	35.0	−10 48	350	− 4	8.9	B2nk	11	−13.9	3.3	+ 3 (4)		
172510.....	35.5	−14 51	346	− 6	8.81	B2k	6	− 6.0	1.3	− 2 (3)		
172637.....	36.2	− 8 10	352	− 3	9.7	B4s	8	− 9.1	1.8	.....		
172694.....	36.5	−15 57	345	− 7	8.3	B3e	6	−29.0	3.3	−15 (5)	M	R
173003.....	38.1	− 1 44	358	0	7.7	B4s	6	−11.2	5.3	.....	var?	
173006.....	38.1	− 5 53	355	− 2	9.9	B3nk	7	−35.1	1.9	−11 (3)		
173011.....	38.1	−11 36	350	− 5	8.9	B5	6	− 4.2	3.3	.....		
173198.....	39.0	− 1 39	358	− 1	8.1	B3n	6	−21.7	2.7	.....		R
173219.....	39.1	− 7 13	354	− 3	8.3	B1ek	6	+ 5.6	14.6	.....	var M	R
173251.....	39.2	−14 28	347	− 7	8.8	B3n	5	−45.8	7.8	.....	var	
173375.....	39.8	−17 39	344	− 8	7.06	B4	9	−11.6	3.0	.....		
173438.....	40.2	− 4 42	356	− 2	8.1	B0	7	− 3.6	10.1	.....	var	R
173637.....	41.2	− 8 02	353	− 4	9.2	B0e	5a, b	−46.	7.	.....		R
173850.....	42.4	− 7 09	354	− 4	9.2	B8	7a, b	−17.4	5.2	.....	var?	
173987.....	43.2	− 6 34	354	− 4	9.1	B1k	5a, b	+39.8	± 6.2	+20 (4)	var?	

TABLE 2—*Continued*

HD	α (1900)	δ (1900)	l	b	Mag.	Spec.	Number of Plates	Vel.	P.E.	K Vel.	Remarks	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
173991	18h43m2	−12° 40′	349°	− 7°	8.7	B4	5	−16.2	± 3.1	.....		
174069	43.6	− 8 34	353	− 5	7.64	B2sk	7	+ 6.0	1.4	−21)6)		
174070	43.6	−12 42	349	− 7	9.1	B4	9a, b	− 5.4	6.4	.....		R
174083	43.7	− 8 16	353	− 5	10.3	B4n	6b	−24.6	2.5	.....		
174182	44.2	− 0 30	0	− 1	8.3	B3n	6	−15.8	5.0	.....		
174243	44.5	− 7 46	354	− 5	10.1	B3k	6b	−16.0	3.3	−13 (6)		
174513	45.7	− 7 54	354	− 5	8.9	B1ek	5	− 7.2	2.1	− 7 (5)		R
174705	46.7	−11 45	350	− 7	7.9	B3nk	6	− 5.6	1.8	−20 (2)		
174902	47.8	− 7 12	354	− 5	9.7	B4s	6	− 6.1	2.2	.....		
175141	48.9	−19 59	343	−11	8.88	B9	5	+ 5.5	6.3	.....	var?	
175544	50.7	+ 0 08	1	− 2	7.73	B5	6	− 4.1	1.3	.....		R
175754	51.7	−19 17	344	−11	7.03	B0n(e)k	7	−11.4	1.2	− 3 (6)		R
175876	52.3	−20 33	343	−12	6.73	O8nk	8	+ 3.9	4.4	.....	V +23.9 SB	R
176630	56.1	− 6 20	356	− 6	7.69	B4n	8	− 7.1	3.2	.....		
177014	57.7	−19 34	344	−13	9.7	B8	8	− 8.3	1.8	.....		
177015	57.7	−20 16	344	−13	7.57	B3e	6	+ 6.1	2.4	.....	M	R
177284	58.9	− 2 10	0	− 5	8.7	B3nk	6	− 6.2	4.2	− 5 (4)		
177559	19 00.1	−19 38	345	−13	8.1	B5n	6	−27.	29.	.....	var	R
177752	00.9	− 0 59	2	− 5	8.5	B4	5	+ 6.8	2.2	.....		
177989	01.8	−18 53	346	−13	9.6	B4	6a, b	+ 0.1	1.8	.....		
178487	03.7	−10 22	354	−10	8.7	B0k	6	−49.8	1.7	−31 (6)		
178861	05.1	−12 38	352	−11	8.3	B5	6	− 9.2	5.3	.....	var?	
179405	07.3	− 6 38	357	− 9	8.6	B5e	6	−23.8	6.6	.....		R
179407	07.3	−12 45	352	−12	9.3	B2n(k)	7a, b	−89.8	5.8	.....	var?	
180126	10.2	+ 9 37	12	− 2	7.9	B4	5	−15.9	5.3	.....		R
180587	12.0	+10 49	13	− 2	8.1	B4s	5	− 9.9	3.7	.....		
180629	12.1	−17 07	348	−15	7.9	B5	6	−10.9	2.2	.....		
182975	22.2	− 2 13	3	−10	8.22	B3	5	− 1.4	2.2	.....		
183129	22.9	− 1 18	4	−10	8.3	B8	5	− 1.9	0.9	.....		
183133	22.9	−15 18	351	−16	6.73	B3n	8	−24.0	9.0	.....	var	R
183570	25.1	−16 23	350	−17	7.25	B6	6	− 4.4	4.3	.....		
185534	34.4	−21 32	346	−21	8.1	B5	8	−12.0	1.7	.....		
185842	36.0	− 2 33	4	−14	7.12	B5s	6	−16.4	4.5	.....	var V −1.0	
186182	37.8	+15 02	20	− 5	8.04	B5	5	− 8.7	1.7	.....		
186272	38.3	+17 44	22	− 4	7.9	B4	5	−19.8	4.5	.....		
186610	40.3	− 3 24	4	−15	9.1	B3n(k)	6	+21.5	1.2	.....		
187350	44.4	− 1 21	6	−15	8.7	B0ek	6	+15.0	1.9	−12 (6)		R
188618	50.9	−18 11	351	−24	9.2	B4	6a, b	−14.8	2.8	.....		
206144	21 35.0	−18 03	3	−47	9.1	B3n	6	+75.6	3.2	.....		
210191	22 03.5	−19 01	6	−53	5.74	B2sk	6	− 5.2	0.4	−10 (5)		
212044	16.4	+51 21	68	− 5	7.08	B2ek	4	−14.4	1.9	−15 (4)	V −15.2	
214080	30.7	−16 54	14	−58	6.69	B2ssk	6	0.0	4.1	+ 5 (5)	var	
220172	23 16.6	−10 18	38	−64	7.54	B3s	7	+12.6	± 0.9	.....		

NOTES TO TABLE 2

HD 886 γ Pegasi, standard-velocity star

20340 The 82 spectrograms taken on 52 nights show a range of 100 km/sec. From 6 to 11 lines are available for radial velocity measurement. These lines change in appearance. Type ranges from B3n to B8(e). The plates were measured by both observers with the following results:

−23.8± 1.7 km/sec	Miss Roosen Raad	82 plates
−25.6± 1.3	Neubauer	82 plates

The weighted mean for the measures reduced to the Lick system is undoubtedly close to the velocity of the system. Attempts to derive a period are thus far without success

23338 q Tauri

25638, 25639 +61°676, np and sf respectively; taken by request for Dr. Hertzsprung

30836 π^4 Orionis, standard-type star. SB orbit by Baker, *Pub. Allegheny Obs.*, **1**, 107, 1909. Our measures fit Baker's curve satisfactorily

35468 γ Orionis

36954 Orbit by Neubauer, *Lick Obs. Bull.*, **17,** 185–191, 1936

37000 Orbit by Neubauer, *Pub. A.S.P.*, **49,** 126, 1937

37115 Merrill's No. 114. Emission extends to *Hδ*

37128 ε Orionis

42259 Range 120 km/sec from poor absorption lines, chiefly 4026, 4471. The spectrum is not suitable for radial velocity measures. Emission lines are about equal in density to that of the continuous spectrum

44743 β Canis Majoris

46380 Distinct emission lines. Sharp interstellar K line
47761 Distinct emission lines. Velocity range 70 km/sec. Good lines
48282 Distinct emission lines. Absorption lines fuzzy
49888 Bandlike emission
49977 Merrill's No. 154
50891 Lines faint and difficult to measure
51193 Distinct emission lines. K line sharp
51452 Faint emission suspected. Lines difficult to measure
52244 Merrill's No. 163
52721 Merrill's No. 164
52942 Two spectra. Range nearly 40 km/sec
53179 Merrill's No. 165 (Z CMa)
53857 A and B, Hussey 48. Visual double star
54575 Distinct emission lines. Variable velocity based upon fairly sharp absorption lines
55135 Merrill's No. 168
55394 Distinct emission lines on two plates
56310 Orbit by Neubauer and Miss Roosen Raad, *Lick Obs. Bull.*, **19,** 95, 1940
57370 Visual double star, GC 5997
59497 Merrill's No. 181
59543 Orbit by Neubauer and Miss Roosen Raad, *Lick Obs. Bull.*, **19,** 97, 1940
60260 Distinct emission
60855 Faint emission lines on several plates
62532 Emissions on a nearly continuous background
62678 Distinct emission. Good spectrum
62729 Distinct emission on four plates
64298 Distinct emission. The difference between the violet and red components of the hydrogen absorption lines is nearly 300 km/sec
65307 Range 220 km/sec
68468 *Mt. W. Contr.* No. 591 classifies this star Ape; velocity +12 km/sec from one plate
71518 Traces of a secondary spectrum
89884 $H\beta$ faintly emission-like on three plates
149363 High velocity ranges from 80 to 120 km/sec. Numerous good lines
158319 Merrill's No. 260
160762 ι Herculis. Standard-velocity star
161961 *Mt. W. Contr.* No. 591. Good lines
166182 102 Herculis. Standard-velocity star
166188 Merrill's No. 282
166443 Faint emission. Unusually wide 4471
166566 Merrill's No. 284
166568 Distinct emission
166666 Merrill's No. 285
166934 Double lines
167287 Range 80 km/sec
167311 Distinct emission on two plates
167330 Double lines
167451 Double lines on two plates
168183 Range 150 km/sec
169753 RZ Scuti. Range 170 km/sec. This star is still under observation here for radial velocity
169754 Range 140 km/sec
169755 A visual double star on slit of spectrograph
170061 Merrill's No. 298
170452 Composite spectrum
171012 Merrill's No. 301
171198 Emission spectrum?
171348 Merrill's No. 302
172175 Traces of emission. Range 100 km/sec
172256 Poor spectrum. Emission? "Washed out" hydrogen lines
172367 Poor spectrum, shallow lines
172694 Merrill's No. 303. In appearance a good deal like the two preceding stars
173198 Secondary spectrum on two plates
173219 Merrill's No. 304
173438 Two spectra
173637 Almost continuous
174070 Poor spectrum. Range 70 km/sec. $H\gamma$ appears double
174513 Distinct emission
175754 Traces of emission on all plates
175876 Victoria binary
177015 Merrill's No. 309
177559 Wide shallow lines. Range of 200 km/sec in our measures. Spectrum not suitable for radial velocity determination
179405 Distinct emission
180126 Poor lines
183133 Range 110 km/sec
187350 Distinct emission

A PHOTOELECTRIC LIGHT-CURVE FOR THE WOLF-RAYET ECLIPSING BINARY HD 193576*

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ABSTRACT

A light-curve for the Wolf-Rayet eclipsing binary HD 193576 has been determined with a photoelectric cell (λ_{eff} = 4500 A). The observations confirm the period, $4^d.21238$, derived by O. C. Wilson from the variation in radial velocity but show a discrepancy of $-0^d.022$ between his epoch of conjunction and the epoch of primary minimum. The depth of primary minimum is $0^m.297$ and that of secondary minimum is $0^m.141$. Between eclipses the light of the system appears to be constant within the errors of observation. The probable error of a single normal point is $\pm 0^m.003$. The width of primary minimum is at least twice the width of secondary minimum. Secondary minimum is displaced $-0^d.011$ from the midpoint of the period. The authors have been unable to interpret the observed light-curve on a purely geometrical basis; therefore no elements except the epoch of primary minimum are derived.

In 1939 O. C. Wilson announced[1] that the Wolf-Rayet star HD 193576 is a spectroscopic binary with both spectra visible. The following year he published[2] orbits for the two components, of spectral class WN5 and early B type, respectively. He remarked that, in view of the short period, $4^d.21238$, and the large variation in velocity, photometric observations for the purpose of finding out whether the star is an eclipsing variable were highly desirable. Acting upon the suggestion, Kron began photoelectric observations at Mount Hamilton in July, 1940. At the September meeting of the American Astronomical Society, S. Gaposchkin gave the preliminary results[3] of his photometric observations on Harvard patrol plates, which showed that the star is an eclipsing binary with the Wolf-Rayet component in front at primary minimum. His solution[4] was so indeterminate that Wilson[5] attempted to give a more definite picture of the system by a study of spectral-line profiles at different phases. From the observed small difference in intensity of the lines in and out of eclipse, he concluded that the eclipses are by no means total.

The 1940 photoelectric observations indicated that a more accurate light-curve than Gaposchkin's would give valuable additional information. A continuation of the investigation was therefore planned, but it had to be interrupted when Kron was called for war research. The work was resumed during his temporary return in May, 1942, and a total of 360 observations was made. Miss Gordon then continued the observing and completed the investigation.

OBSERVATIONS

All the observations were made with the blue-sensitive photoelectric photometer of the Lick Observatory.[6] The comparison star was chosen with the following criteria in mind: proximity to the variable, similar spectral type, nearly the same brightness, and, of course, no evidence of variability. HD 193514 fulfilled these requirements; and, since the observations confirmed the assumption of its nonvariability, the use of other comparison stars in the observing program seemed unnecessary. Data for HD 193514 and HD 193576 are given in Table 1.

* *Contributions from the Lick Observatory*, Ser. II, No. 7.

[1] *Pub. A.S.P.*, **51**, 55, 1939.

[2] *Ap. J.*, **91**, 379, 1940.

[3] *Pub. A.A.S.*, **10**, 52, 1940.

[4] *Ap. J.*, **93**, 202, 1941.

[5] *Ap. J.*, **95**, 402, 1942.

[6] *Lick Obs. Bull.*, **19**, 53, 1939.

The observing technique was to alternate five galvanometer deflections on the comparison star with ten deflections on the variable. After the means of the deflections were corrected for the effect of the night sky, the mean of preceding and following comparison-star observations was subtracted from the observation of the variable. This difference, converted into magnitude and plotted against the corresponding phase, gives the observed light-curve. Observations Nos. 1–266 were made with a rotating sector on the comparison star, which reduced its light by $0^m.498$. There was some evidence from the probable errors of observation during the course of a night that the sector's extinction was not constant. Therefore, beginning with observation No. 267, a piece of Schott NG5 filter glass, 1 mm thick, was substituted for the sector. Since then the observations tended to be more uniform. A comparison of results obtained with the filter and the sector gave a difference (filter−sector) of $-0^m.317$, and all values of Δm following observation No. 266 have been reduced by this amount. In the spring of 1940 someone accidentally moved the galvanometer, causing its response to be nonlinear. The experimentally determined correction for nonlinearity within the observed range of the difference in deflection between the comparison star and the variable was equal to $0^m.0006 \times (\Delta$ deflection in millimeters); observations Nos. 1–207 have been corrected by this amount.

TABLE 1

Name	R.A.	Decl.	Mag.	Spec.
HD 193514.....	$20^h15^m.5$	$+38°57'$	$7^m.29$	B2
HD 193576.....	20 15.8	+38 25	8.04	WN5, O6*

* C. S. Beals, paper presented before the American Astronomical Society, December, 1942.

Table 2 gives the results of the investigation. The second column contains the Julian date of observation in heliocentric Greenwich mean time, and the third column, the corresponding heliocentric phase as computed from the formula

$$JD = 2428771.335 + 4^d.21238E .$$

The photoelectric observations indicate a difference of $-0^d.022$ between the epoch of conjunction as derived by Wilson and the epoch of primary minimum. His period, however, satisfactorily represents the photoelectric data. The fourth column contains the difference in magnitude between the comparison star and the variable in the sense HD 193514 − HD 193576. The values of Δm include the corrections noted above and a further small correction for differential extinction due to the difference in zenith distance between the two stars. The observations in parentheses have been rejected in the discussion, Nos. 716–751 because the lock joint between the photometer and the telescope was loose at the time, No. 7 because of discordance, and the others because of interference either by clouds or by the dome.

RESULTS

The mean value of Δm outside of eclipse is $-0^m.089 \pm 0^m.001$ for the 1940 observations, and $-0^m.095 \pm 0^m.001$ for those of 1942. The systematic difference between the two series also appears in observations of secondary minimum, which was well observed in both years. At least part of this difference may be explained by an erroneous value for the relative extinction of the sector and the filter. Before computing the normal points discussed below, the 1940 observations were corrected by $-0^m.006$ to make the material homogeneous.

TABLE 2

PHOTOMETRIC OBSERVATIONS OF HD 193576 AT λ 4500

No.	JD 242	Heliocentric Phase	Δm	No.	JD 242	Heliocentric Phase	Δm
1.....	9811d898	0d061	−0m318	50.....	9832d781	4d095	−0m305
	.907	0.070	.332		.789	4.103	.334
	.932	0.095	.312		.801	4.115	.317
	9813.896	2.059	.213		.809	4.123	.310
					9834.704	1.805	.060
5.....	.904	2.067	.211				
	.924	2.087	.229	55.....	.711	1.812	.061
	.944	2.107	(.203)		.717	1.818	.075
	.953	2.116	.212		.725	1.826	.089
	.962	2.125	.204		.735	1.836	.080
					.742	1.843	.073
10.....	.970	2.133	.201				
	9816.878	0.829	(.100)	60.....	.748	1.849	.070
	9823.743	3.281	.092		.759	1.860	.086
	.751	3.289	.098		.766	1.867	.104
	.757	3.295	.104		.776	1.877	.092
					.787	1.888	.092
15.....	.764	3.302	.083				
	.777	3.315	.101	65.....	.795	1.896	.097
	.785	3.323	.103		.822	1.913	.109
	.793	3.331	.107		.829	1.920	.110
	.803	3.341	.101		9835.905	3.006	.101
					.912	3.013	.089
20.....	.810	3.348	.092				
	.816	3.354	.116	70.....	.919	3.020	.101
	.828	3.366	.097		.932	3.033	.110
	9826.849	2.375	.109		.939	3.040	.094
	.855	2.381	.088		.945	3.046	.092
					.956	3.057	.105
25.....	.863	2.389	.113	75.....	.963	3.064	.095
	9828.711	0.025	.377		.970	3.071	.098
	.719	0.033	.374		.977	3.078	.099
	.726	0.040	.379		9841.893	0.569	.111
	.737	0.051	.353		.899	0.575	.108
30.....	.744	0.058	.356	80.....	.905	0.581	.116
	.751	0.065	.345		.913	0.589	.113
	.763	0.077	.330		.919	0.595	.113
	.771	0.085	.325		.926	0.602	.100
	.777	0.091	.318		.934	0.610	.102
35.....	.791	0.105	.316	85.....	.939	0.615	.110
	.797	0.111	.291		.947	0.623	.126
	.805	0.119	.277		.954	0.630	.127
	.814	0.128	.269		9844.896	3.572	.089
	.845	0.159	.257		.903	3.579	.094
40.....	9832.706	4.020	.215	90.....	.910	3.586	.090
	.712	4.026	.222		.917	3.593	.086
	.719	4.033	.230		.925	3.601	.085
	.729	4.043	.244		.932	3.608	.093
	.735	4.049	.248		.939	3.615	.088
45.....	.742	4.056	.244	95.....	9851.887	2.139	.221
	.749	4.063	.261		.895	2.147	.197
	.761	4.075	.294		.901	2.153	.197
	.769	4.083	.276		.909	2.161	.172
	.775	4.089	−0.278		.915	2.167	−0.174

TABLE 2—*Continued*

No.	JD 242	Helio-centric Phase	Δm	No.	JD 242	Helio-centric Phase	Δm
100.....	9851^{d}927	2^{d}179	−0^{m}166	150.....	9862^{d}777	0^{d}392	−0^{m}138
	.935	2.187	.154		.785	0.400	.122
	.940	2.192	.147		.814	0.429	.123
	.948	2.200	.124		.821	0.436	.134
	.955	2.207	.110		.827	0.442	.121
105.....	.961	2.213	.141	155.....	9867.803	1.205	.071
	.969	2.221	.126		.810	1.212	.074
	.976	2.228	.115		.817	1.219	.073
	9853.726	3.978	.196		.824	1.226	.073
	.733	3.985	.206		.831	1.233	.070
110.....	.739	3.991	.221	160.....	9869.689	3.091	.078
	.746	3.998	.221		.697	3.099	.081
	.753	4.005	.237		.704	3.106	.080
	.777	4.029	.234		.731	3.133	.082
	.784	4.036	.237		.737	3.139	.074
115.....	.802	4.054	.249	165.....	9891.704	4.044	.237
	.810	4.062	.271		.711	4.051	.260
	.835	4.087	.309		.734	4.074	.271
	.841	4.093	.322		.742	4.082	.301
	.848	4.100	.331		.749	4.089	.290
120.....	9859.795	1.622	.074	170.....	.757	4.097	.314
	.819	1.646	.096		.768	4.108	.307
	.826	1.653	.096		.776	4.116	.318
	.834	1.661	.094		.784	4.124	.323
	.848	1.675	.088		.792	4.132	.331
125.....	.855	1.682	.085	175.....	.804	4.144	.362
	.863	1.690	.080		.812	4.152	.338
	.870	1.697	.077		.821	4.161	.343
	.882	1.709	.083		.829	4.169	.332
	.891	1.718	.085		9893.753	1.881	.105
130.....	.896	1.723	.085	180.....	.761	1.889	.111
	.909	1.736	.097		.768	1.896	.098
	.916	1.743	.090		.775	1.903	.111
	.924	1.751	.086		.783	1.911	.090
	.931	1.758	.073		.790	1.918	.096
135.....	9861.683	3.510	.081	185.....	.796	1.924	.086
	.688	3.515	.072		9895.717	3.845	.110
	.696	3.520	.070		.728	3.854	.135
	.709	3.536	.065		.734	3.860	.142
	.715	3.542	.069		.748	3.874	.159
140.....	.721	3.548	.073	190.....	.756	3.882	.140
	.763	3.590	.068		.763	3.889	.153
	9862.678	0.293	.148		.772	3.898	.147
	.685	0.300	.162		.782	3.908	.150
	.692	0.307	.140		.790	3.916	.161
145.....	.701	0.316	.138	195.....	.800	3.926	.153
	.709	0.324	.138		.807	3.933	.143
	.715	0.330	.142		9897.789	1.705	.066
	.722	0.337	.133		.796	1.712	.078
	.730	0.345	−0.133		.804	1.720	−0.069

TABLE 2—*Continued*

No.	JD 242	Helio-centric Phase	Δm	No.	JD 242	Helio-centric Phase	Δm
200	9897^{d}812	1^{d}728	−0^{m}072	250	9914^{d}732	1^{d}798	−0^{m}093
	.824	1.740	.077		.740	1.806	.081
	9898.750	2.666	.059		.747	1.813	.095
	.757	2.673	.072		.777	1.843	.094
	.766	2.682	.057		.785	1.851	.099
205	.772	2.688	.066	255	.793	1.859	.087
	.780	2.696	.064		9948.635	2.002	.188
	.787	2.703	.066		.642	2.009	.192
	9906.695	2.186	.155		.649	2.016	.211
	.703	2.194	.149		.657	2.024	.195
210	.709	2.200	.137	260	.664	2.031	.212
	.717	2.208	.105		.671	2.038	.213
	.724	2.215	.112		.679	2.046	.207
	.731	2.222	.113		.686	2.052	.225
	.776	2.247	.094		.693	2.060	.226
215	.784	2.255	.088	265	.701	2.068	.226
	.793	2.264	.099		.707	2.074	.233
	.800	2.271	.096		.723	2.090	.237
	.808	2.279	.087		.730	2.097	.229
	.814	2.285	.074		.737	2.104	.213
220	.822	2.293	.085	270	9956.645	1.587	.104
	9911.711	2.989	.086		.652	1.594	.100
	.719	2.997	.089		.660	1.602	.109
	.748	3.026	.104		.668	1.610	.092
	.755	3.033	.107		.676	1.618	.099
225	.785	3.063	.098	275	.682	1.624	.114
	.792	3.070	.090		.699	1.641	.111
	.800	3.078	.094		.706	1.648	.105
	9912.693	3.971	.188		.712	1.654	.099
	.700	3.978	.199		9969.633	1.938	.149
230	.707	3.985	.201	280	.642	1.945	.156
	.714	3.992	.179		.648	1.953	.142
	.722	4.000	.184		.656	1.961	.163
	.728	4.006	.184		.664	1.969	.184
	.736	4.014	.192		.678	1.983	.201
235	.743	4.021	.228	285	10514.871	3.779	.127
	.751	4.029	.225		.884	3.792	.123
	.759	4.037	.233		.898	3.806	.118
	.766	4.044	.219		.909	3.817	(.107)
	.773	4.051	.242		10521.840	2.323	.122
240	.779	4.057	.238	290	.849	2.332	.123
	.788	4.066	.232		.862	2.345	.113
	.795	4.073	.262		.874	2.357	.111
	.803	4.081	.270		.880	2.363	.086
	9914.689	1.755	.088		.894	2.377	.105
245	.697	1.763	.084	295	.903	2.386	.110
	.704	1.770	.084		.914	2.397	.086
	.710	1.776	.084		.951	2.434	.115
	.718	1.784	.081		.963	2.446	.079
	.725	1.791	−0.079		10523.829	0.100	−0.306

TABLE 2—*Continued*

No.	JD 243	Helio-centric Phase	Δm	No.	JD 243	Helio-centric Phase	Δm
300	0523^d.838	0^d.109	−0^m.306	350	0543^d.898	3^d.319	−0^m.110
	.850	0.121	.302		0544.781	4.202	.387
	.860	0.131	.307		.791	0.000	.414
	.868	0.139	.289		.802	0.011	.413
	.874	0.145	.259		.811	0.020	.405
305	.888	0.159	.271	355	.819	0.028	.395
	.896	0.167	.271		.829	0.038	.399
	.903	0.174	.243		.837	0.046	.358
	.911	0.182	.232		.844	0.053	.393
	.920	0.191	.237		.857	0.066	.341
310	.943	0.214	.202	360	.866	0.075	.332
	.951	0.222	.203		0558.720	1.292	.093
	.959	0.230	.180		.729	1.301	.107
	0528.781	0.840	.098		.737	1.309	.091
	.789	0.848	.096		.748	1.320	.099
315	.796	0.855	.085	365	.755	1.327	.085
	.804	0.863	.091		.765	1.337	.087
	.818	0.877	.107		.775	1.347	.091
	.824	0.883	.104		.783	1.355	.095
	.834	0.893	.103		.791	1.363	.089
320	.842	0.901	.108	370	.799	1.371	.080
	.850	0.909	.109		.806	1.378	.094
	.858	0.917	.107		.813	1.385	.086
	.866	0.924	.104		.853	1.425	.087
	.874	0.933	.113		.861	1.433	.098
325	.881	0.940	.109	375	.884	1.456	.089
	.890	0.949	.113		.893	1.465	(.059)
	0530.815	2.874	.090		.913	1.485	.091
	.821	2.880	.099		.924	1.496	.091
	.830	2.889	.085		.931	1.503	.095
330	.837	2.896	.091	380	.941	1.513	.099
	.844	2.903	.093		.949	1.521	.107
	.852	2.911	.091		0561.719	0.079	.333
	.861	2.920	.097		.729	0.089	.310
	.865	2.929	.093		.737	0.097	.285
335	.877	2.936	.098	385	.745	0.105	.293
	.885	2.944	.095		.755	0.115	.279
	.893	2.952	.090		.763	0.123	.270
	0532.813	0.659	.114		.770	0.130	.292
	.823	0.669	.130		.778	0.138	.288
340	.835	0.681	.121	390	.788	0.148	.244
	.843	0.689	.113		.795	0.155	.241
	.857	0.703	.111		.805	0.165	.221
	.870	0.716	.127		.811	0.171	.209
	0543.813	3.234	.133		.840	0.200	.189
345	.825	3.246	.131	395	.847	0.207	.202
	.835	3.256	.132		.876	0.236	.166
	.843	3.264	.119		.905	0.265	.162
	.855	3.276	.119		.913	0.273	.174
	.865	3.286	−0.136		.921	0.281	−0.189

TABLE 2—*Continued*

No.	JD 243	Helio-centric Phase	Δm	No.	JD 243	Helio-centric Phase	Δm
400	0561.929	0.289	−0.165	450	0576.940	2.662	−0.094
	.938	0.298	.152		.949	2.671	.088
	.945	0.305	.135		.956	2.678	.095
	.955	0.315	.149		.965	2.687	.088
	0563.739	2.099	.233		.975	2.697	.081
405	.752	2.112	.240	455	.984	2.706	.088
	.761	2.121	.240		0583.819	1.117	.093
	.770	2.130	.235		.843	1.141	.091
	.777	2.137	.225		.850	1.148	.094
	.790	2.150	.235		.858	1.156	.093
410	0572.706	2.641	.100	460	.867	1.165	.111
	.716	2.651	.099		.874	1.172	.107
	.724	2.659	.101		.881	1.179	.095
	.732	2.667	.104		.891	1.189	.094
	.740	2.675	.106		.897	1.195	.102
415	.749	2.684	.080	465	.904	1.202	.099
	.760	2.695	.112		.913	1.211	.108
	.769	2.704	.104		.920	1.218	.107
	.884	2.819	.093		.928	1.226	.088
	.894	2.829	.092		.936	1.234	.120
420	.903	2.838	.084	470	.943	1.241	.118
	.912	2.847	.088		.950	1.248	.105
	.921	2.856	.091		.961	1.259	.104
	.927	2.862	.099		0584.689	1.987	.153
	.935	2.870	.109		.701	1.999	.171
425	.943	2.878	.104	475	.711	2.009	.185
	.949	2.884	.095		.717	2.015	.198
	.959	2.894	.093		.726	2.024	.200
	.966	2.901	.090		.733	2.031	.217
	.975	2.910	.101		.744	2.042	.220
430	0575.863	1.585	.085	480	.773	2.071	.244
	.873	1.595	.100		.779	2.077	.227
	.881	1.603	.102		.787	2.085	.235
	.887	1.609	.107		.808	2.106	.229
	.895	1.617	.106		.814	2.112	.237
435	.902	1.624	.103	485	.837	2.135	.224
	.913	1.635	.114		.843	2.141	.249
	.921	1.643	.086		.850	2.148	.230
	.928	1.650	.099		.858	2.156	.210
	.936	1.658	(.131)		.865	2.163	.219
440	.945	1.667	(.117)	490	.873	2.171	.223
	.952	1.674	(.108)		.880	2.178	(.196)
	0576.871	2.593	.079		0586.694	3.992	.219
	.887	2.609	.094		.704	4.002	.240
	.894	2.616	.072		.709	4.007	.217
445	.899	2.621	.077	495	.716	4.014	.227
	.907	2.629	.103		.724	4.022	.242
	.913	2.635	.088		.731	4.029	.256
	.923	2.645	.079		.738	4.036	.269
	.932	2.654	−0.086		.745	4.043	(−0.245)

TABLE 2—*Continued*

No.	JD 243	Helio-centric Phase	Δm	No.	JD 243	Helio-centric Phase	Δm
500.....	0586^{d}774	4^{d}072	−0^{m}277	550.....	0591^{d}841	0^{d}714	−0^{m}104
	.784	4.082	.305		.849	0.722	.091
	.808	4.106	.341		.856	0.729	.098
	.815	4.113	.332		.865	0.738	.102
	.833	4.131	.372		.871	0.744	.116
505.....	.839	4.137	.379	555.....	.880	0.753	.095
	.846	4.144	.377		.891	0.764	.090
	.855	4.153	.387		.897	0.770	.098
	.863	4.161	.378		.906	0.779	.108
	.870	4.168	.377		.914	0.787	.081
510.....	.877	4.175	.388	560.....	0599.677	0.125	.298
	.884	4.182	.380		.689	0.137	.291
	.893	4.191	.387		.697	0.145	.285
	.899	4.197	.396		.709	0.157	.243
	.907	4.204	.395		.715	0.163	.245
515.....	.913	4.210	.390	565.....	.734	0.182	.231
	.921	0.006	.395		.741	0.189	.231
	.927	0.012	.375		.751	0.199	.217
	.939	0.024	.359		.769	0.217	.213
	.947	0.032	.382		.776	0.224	.214
520.....	0590.684	3.769	.105	570.....	.805	0.253	.209
	.693	3.778	.117		.813	0.261	.197
	.701	3.786	.107		.821	0.269	.185
	.709	3.794	.134		.829	0.277	.188
	.717	3.802	.115		0601.677	2.125	.265
525.....	.725	3.810	.115	575.....	.687	2.135	.264
	.733	3.818	.138		.695	2.143	.242
	.757	3.842	.135		.701	2.149	.248
	.765	3.850	.140		.711	2.159	.207
	.773	3.858	.135		.728	2.176	.202
530.....	.795	3.880	.138	580.....	.735	2.183	.204
	.803	3.888	.142		.742	2.190	.197
	.825	3.910	.161		.767	2.215	.162
	.832	3.917	.162		.777	2.225	.163
	.839	3.924	.167		.792	2.240	.169
535.....	.846	3.931	.167	585.....	.799	2.247	.141
	.853	3.938	.159		.805	2.253	.140
	.861	3.946	.158		.814	2.262	.130
	.869	3.954	.169		.820	2.268	.129
	.878	3.963	.183		.829	2.277	.124
540.....	.885	3.970	.168	590.....	.835	2.283	.127
	.894	3.979	.180		.843	2.291	.121
	.900	3.985	.186		.850	2.298	.114
	.909	3.994	.196		.860	2.308	.113
	.917	4.002	.194		.868	2.316	.100
545.....	.924	4.009	.191	595.....	.881	2.329	.105
	.932	4.017	.212		.889	2.237	.106
	0591.819	0.692	.071		0602.685	3.133	.093
	.828	0.701	.097		.695	3.143	.094
	.835	0.708	−0.104		.703	3.151	−0.091

TABLE 2—*Continued*

No.	JD 243	Heliocentric Phase	Δm	No.	JD 243	Heliocentric Phase	Δm
600	0602^{d}710	3^{d}158	−0^{m}101	650	0618^{d}698	2^{d}297	−0^{m}109
	.725	3.173	.102		.719	2.318	.085
	.735	3.183	.091		.749	2.348	.093
	.743	3.191	.072		.756	2.355	.085
	.763	3.211	.069		.764	2.363	.097
605	.773	3.221	.070	655	.771	2.370	.098
	.791	3.239	.075		.779	2.378	.098
	.797	3.245	.075		.788	2.387	.087
	.805	3.253	.072		.811	2.410	.086
	.813	3.261	.072		.817	2.416	.074
610	.821	3.269	.061	660	.824	2.423	.091
	.827	3.275	.061		.832	2.431	.087
	.835	3.283	.065		.839	2.438	.091
	0603.680	4.128	.320		0649.727	3.839	.160
	.689	4.137	.307		.734	3.846	.147
615	.697	4.145	.329	665	.742	3.854	.157
	.703	4.151	.347		0653.650	3.550	.123
	.719	4.167	.342		.659	3.559	.075
	.728	4.176	.360		.669	3.569	.075
	.735	4.183	.372		.679	3.579	.116
620	.743	4.191	.367	670	.687	3.587	.098
	.764	0.000	.371		.695	3.595	.099
	0605.685	1.921	.128		.703	3.603	.095
	.695	1.931	.121		.709	3.609	.101
	.711	1.947	.148		.720	3.620	.103
625	.719	1.955	.143	675	.728	3.628	.136
	.726	1.962	.157		.735	3.635	.130
	.733	1.969	.164		.743	3.643	.127
	.755	1.991	.192		.751	3.651	.106
	0610.675	2.698	.099		.762	3.662	.132
630	.682	2.705	.081	680	0661.638	3.113	.098
	.704	2.727	.112		.647	3.122	.097
	.710	2.733	.087		.656	3.131	.094
	.716	2.739	.095		.664	3.139	.103
	0614.662	2.473	.105		.676	3.151	.088
635	.670	2.481	.113	685	.683	3.158	.103
	.689	2.500	.102		.691	3.166	.107
	.698	2.509	.093		.699	3.174	.108
	.704	2.515	.087		.708	3.183	.106
	.730	2.541	.089		.718	3.193	.098
640	.738	2.549	.087	690	.726	3.201	.097
	.752	2.563	.083		.734	3.209	.112
	.762	2.573	.091		0663.639	0.901	.093
	.772	2.583	.077		.646	0.908	.077
	.778	2.589	.080		.655	0.917	.081
645	.787	2.598	.079	695	.662	0.924	.079
	.794	2.605	.094		.670	0.932	.080
	.802	2.613	.100		.681	0.943	.107
	.810	2.621	.087		.689	0.951	.089
	0618.686	2.285	−0.109		.696	0.958	−0.073

TABLE 2—*Continued*

No.	JD 243	Helio-centric Phase	Δm	No.	JD 243	Helio-centric Phase	Δm
700.....	0663^{d}705	0^{d}967	−0^{m}092	730.....	0673^{d}638	2^{d}476	(−0^{m}073)
	.712	0.974	.086		.646	2.484	(.064)
	.721	0.983	.087		.653	2.491	(.075)
	.730	0.992	.112		.663	2.501	(.084)
	0670.623	3.673	.075		.671	2.509	(.062)
705.....	.632	3.682	.096	735.....	.679	2.517	(.072)
	.640	3.690	.091		.686	2.524	(.078)
	.646	3.696	.093		.693	2.531	(.086)
	.656	3.706	.101		.702	2.540	(.086)
	.665	3.715	.109		0674.607	3.445	(.046)
710.....	.672	3.722	.103	740.....	.616	3.554	(.046)
	.680	3.730	.089		.622	3.460	(.054)
	.688	3.738	.098		.630	3.468	(.039)
	.695	3.745	.108		.637	3.475	(.050)
	.705	3.755	.116		.645	3.485	(.045)
715.....	.713	3.763	.108	745.....	.652	3.490	(.036)
	0671.608	0.446	(.050)		.661	3.499	(.054)
	.619	0.457	(.063)		.669	3.507	(.037)
	.626	0.464	(.058)		.676	3.514	(.049)
	.634	0.472	(.063)		.684	3.522	(.034)
720.....	.641	0.479	(.066)	750.....	.691	3.529	(.052)
	.650	0.488	(.047)		.699	3.537	(.059)
	.657	0.495	(.073)		0709.592	0.511	.110
	.665	0.503	(.065)		.602	0.521	.092
	.689	0.527	(.078)		.615	0.534	.119
725.....	.697	0.535	(.051)	755.....	.621	0.543	.098
	0673.607	2.445	(.052)		0712.596	3.522	.120
	.614	2.452	(.068)		.604	3.530	.145
	.622	2.460	(.081)		.612	3.538	.115
	.630	2.468	(−0.065)		.620	3.546	−0.130

The normal points were formed by arranging the 714 observations in order of increasing phase and taking the mean of the Δm's and corresponding phases for each ten points. Normal points Nos. 23, 24, 50, and 53 are 11-point means. The probable error of a single observation is $\pm 0^m009$ and that of a normal, $\pm 0^m003$. The normal points are plotted in Figure 1, which represents the light-curve of HD 193576 in the spectral region λ 4500 A.

Certain features of this curve deserve attention, the most striking of which is the difference in width of the two minima. The width of primary minimum is at least twice that of the secondary. From the present investigation the light of the system outside eclipse would seem to be constant. Further observation might reveal a slight increase in light near secondary minimum, but it could scarcely be greater than 0^m04. The two branches of the curves representing each eclipse appear quite symmetrical, as found when one branch is "reflected" on the other. For secondary minimum the best fit was obtained by this method when the middle of the eclipse was taken at phase 2^d095—a deviation from the mid-point of the period of -0^d011. The depth of primary minimum is estimated as 0^m297 and that of secondary minimum as 0^m141 from the "reflected" light-curves. The light-curves for both minima are unusual in shape, the shoulders of

primary minimum indicating a more gradual decrease in light than usual, while the apparently rounded form of the bottom of secondary minimum is peculiar for a partial eclipse.

TABLE 3

NORMAL POINTS

No.	Phase	Δm	No.	Phase	Δm
1	0^{d}008	−0^{m}390	37	2^{d}286	−0^{m}107
	0.044	.374		2.331	.104
	0.080	.331		2.374	.100
	0.110	.294	40	2.426	.093
5	0.136	.283		2.540	.090
	0.166	.244		2.614	.087
	0.204	.214		2.659	.089
	0.264	.182		2.688	.087
	0.312	.148	45	2.750	.091
10	0.455	.123		2.873	.095
	0.599	.119		2.920	.094
	0.693	.109		3.020	.103
	0.762	.098		3.078	.098
	0.884	.098	50	3.138	.094
15	0.933	.098		3.183	.099
	1.060	.093		3.243	.095
	1.200	.095		3.290	.096
	1.257	.098		3.413	.101
	1.360	.089	55	3.549	.098
20	1.518	.097		3.592	.096
	1.612	.104		3.642	.110
	1.651	.103		3.726	.102
	1.711	.086		3.794	.120
	1.766	.090	60	3.852	.144
25	1.825	.084		3.901	.155
	1.876	.103		3.951	.171
	1.922	.120		3.988	.204
	1.968	.167		4.008	.210
	2.016	.200	65	4.028	.240
30	2.058	.227		4.048	.247
	2.097	.233		4.073	.279
	2.130	.232		4.094	.315
	2.151	.220		4.123	.334
	2.180	.187	70	4.152	.353
35	2.210	.133	71	4.184	−0.375
	2.248	−0.129			

Attempts to make a solution for the photometric elements on a purely geometrical basis, without the assumption of a large orbital eccentricity, have been unsuccessful. Since the spectroscopic evidence eliminates this possible solution, no computed curve will give the observed width of primary minimum or the difference in width of the two minima. It is therefore apparent that the fundamental relationships assumed in Russell's method of deriving the elements from the light-curve of an eclipsing binary do not hold for the system of HD 193576.

The great width of primary minimum shows that the two components must be nearly in physical contact, yet the absence of any considerable reflection effect indicates that their effective radiating surfaces are an appreciable distance apart. These considerations, coupled with the difference in width of the minima point to the presence of some type of envelope around one or both components. The photometric evidence for the existence of an envelope in the system is in accordance with conclusions based upon spectroscopic studies of Wolf-Rayet stars in general and in HD 193576 itself. In a paper presented before the American Astronomical Society in December, 1942, Beals gave the results of his investigation of line profiles in HD 193576 and concluded that the as-

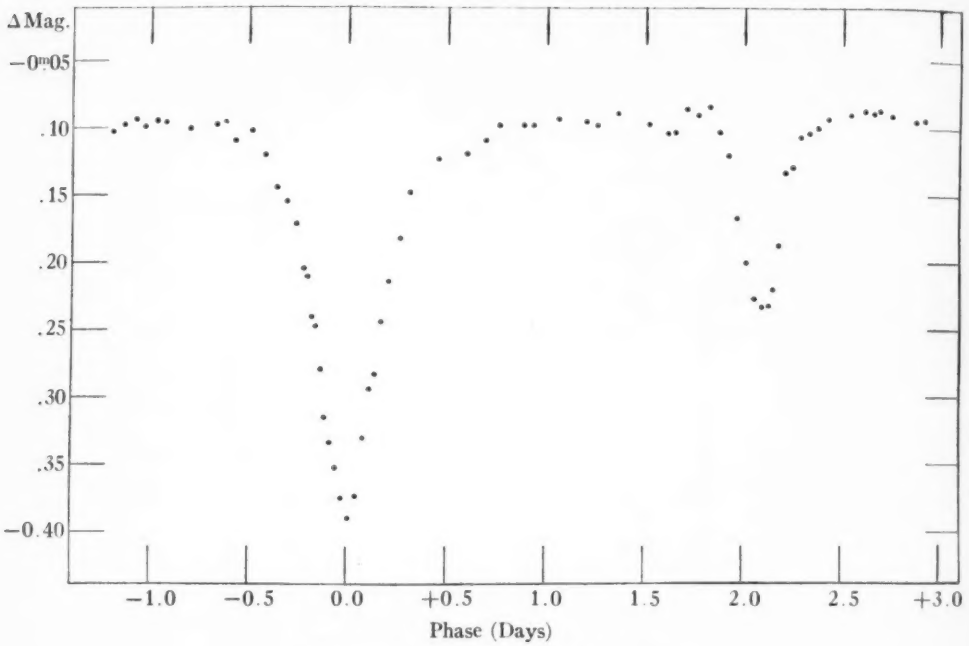

FIG. 1.—Observed light-curve of HD 193576

sumption of an envelope would account for many of the observed peculiarities in the spectrum.

The introduction of this assumption into the solution for the elements requires a knowledge of the envelope's physical characteristics. Observations made with a red-sensitive photoelectric cell might throw some light on the nature and extent of such an envelope; but, until these are available, estimates as to the relative size, surface brightness, or temperature of the components from the present light-curve alone would be quite indeterminate and of little or no practical value. Since we know of no method for computing a light-curve which would represent the photoelectric observations, the data are presented in Figure 1 simply as a plot of the normal points.

The writers wish to thank Mr. C. A. Wirtanen and Mr. G. P. Nagtegaal, who rendered valuable assistance in making the observations, and Dr. C. S. Beals for his kindness in providing a copy of his paper in advance of its publication.

TEMPERATURE CLASSIFICATION OF GADOLINIUM LINES*

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ABSTRACT

Wave-length measures and temperature classifications are given for 5775 lines of gadolinium from λ 2135 to λ 10677. The classification, including a segregation of the lines of *Gd* I and *Gd* II, was obtained by comparing the spectra of the carbon-tube furnace at three temperatures with those of the arc and spark. Features of these spectra in successive wave-length regions are described. The absorption furnace was used to obtain low-level lines of *Gd* I in the ultraviolet to λ 2700. At shorter wave lengths, rich spectra of the arc and spark were photographed with a quartz spectrograph, the spark spectrum in this region giving many lines probably belonging to *Gd* III. These are usually absent from the arc; but some, evidently from low levels, appeared at the arc pole.

A comparison with the solar spectrum showed that approximately 60 lines of *Gd* II are probably present, though sometimes masked, in the sun. These lines are very strong in the arc spectrum and as a rule have considerable strength in the furnace. About half of them are known from preliminary term analysis to arise from low atomic levels.

The classification of gadolinium lines, based upon their relative response to varying degrees of excitation, follows the plan of previous papers on rare-earth spectra.[1] The experimental material, which gave a comparison of electric-furnace spectra at three temperatures with those of the arc and spark, made it possible to distinguish the lines of singly ionized gadolinium, many of which appeared in the furnace spectrum. The purpose has been to include faint lines as far as their characteristics could be told with reasonable certainty. As a result a large proportion of the lines classified had not been previously measured.

EXPERIMENTAL METHOD

Gadolinium, while more easily obtained than some rare earths of higher atomic number, presents unusual difficulties in purification. The writer is greatly indebted to Dr. Herbert N. McCoy, who generously supplied highly purified material prepared in his laboratory in Los Angeles. These compounds contained traces only of terbium and dysprosium, which on account of their rich spectra are usually the most troublesome impurities in preparations of gadolinium. The stronger lines of europium appeared, but their wave lengths and characteristics are well known from a previous study of this spectrum.[2]

While several gadolinium compounds were used, a chloride solution usually gave the best spectra, the arc or spark electrodes as a rule being of "spectroscopically pure" graphite. Silver rods charged with a mixture of gadolinium with silver filings were also used as arc and spark electrodes to eliminate the cyanogen bands.

The carbon-tube furnace was operated at temperatures of approximately 2000°, 2300°, and 2600° C for emission spectra. In the near ultraviolet, absorption spectra also were obtained. For this purpose the continuous radiation from a 50-ampere Philips lamp in a quartz bulb was passed through the furnace tube. Low-level neutral lines then appeared

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[1] *Mt. W. Contr.*, No. 368; *Ap. J.*, **68**, 194, 1928; *Mt. W. Contr.*, No. 414; *Ap. J.*, **72**, 221, 1930; *Mt. W. Contr.*, No. 439; *Ap. J.*, **74**, 328, 1931; *Mt. W. Contr.*, No. 470; *Ap. J.*, **78**, 9, 1933; *Mt. W. Contr.*, No. 523; *Ap. J.*, **82**, 140, 1935; *Mt. W. Contr.*, No. 608; *Ap. J.*, **89**, 377, 1939; *Mt. W. Contr.*, No. 651; *Ap. J.*, **94**, 226, 1941.

[2] *Mt. W. Contr.*, No. 608; *Ap. J.*, **89**, 377, 1939.

in absorption farther in the ultraviolet than at the same temperature in emission. This procedure enabled lines to be placed in class I or class II according to their strength in absorption, while the emission spectrum, showing these lines only at high temperature, would have assigned them to class IV.

The first- and second-order spectra of the 15-foot concave grating were used from λ 2700 to λ 9100, the second-order for the arc and spark to λ 5400 and for the furnace to λ 4700. By the use of a 1-meter concave grating and Eastman I-Q films, infrared lines were photographed to λ 10670. In the ultraviolet, arc and spark spectra were extended to λ 2135 by means of a Hilger E1 quartz spectrograph belonging to the California Institute of Technology. The dispersion of this instrument for the region photographed ranged from 1.51 to 3.53 A/mm.

Wave-length measurements.—Previous lists of gadolinium wave lengths on the international system are those of Eder[3] and, for the long-wave-length region, of Kiess.[4] A considerable number of blue and violet lines had been measured by the writer.[5] Wave lengths for stronger lines are given in the *M.I.T. Wave Length Tables*, which appeared while the present work was in progress. A large part of the earlier Mount Wilson spectrograms were measured by the late E. F. Adams from iron standards. Some of these plates and all the later ones were measured by the writer, the reductions being made by Miss Brayton. From the large amount of material thus available, measures were selected from the plates on which the line in question was best defined, and, if the values were concordant, the wave length is given to three decimal places. In general, two decimals are used for lines measured on first-order plates and for other lines when the precision was not high. For the measurement of very strong lines, spectrograms were used in which collision widening was minimized by the use of low vapor density in the arc.

FEATURES OF THE GADOLINIUM SPECTRUM

The hyperfine patterns of gadolinium, clearly present for many lines, are narrow and show a decided contrast with those found in the spectra of praseodymium, europium, and terbium. Many lines given in the tables as probably double may be complex. While some line intensities are very high, no instances of self-reversal appeared. The small amount of pure gadolinium available prevented the use of high vapor densities in either arc or furnace, but the absence of strong widening of low-level lines, which would permit self-reversal, is characteristic of the spectrum. Features of successive regions for which the experimental procedure differed may now be considered.

λλ *2100–2700.*—For this region, photographed with the quartz spectrograph, only arc and spark spectrograms were made, as the furnace emission spectrum does not extend so far in the ultraviolet. The possible recording of low-level neutral lines in absorption, by means of one of the few continuous sources effective in this region, has not yet been attempted. Table 1 gives wave lengths, arc intensities, and assignment to the neutral or the ionized atom. According to present evidence, all lines in Table 1 belong in class V. A question mark is frequently added to the "E" denoting an ionized line, usually because in the spark spectrum the line is masked by a line probably belonging to *GD* III. As a rule, these probable *Gd* III lines are diffuse in the spark and absent in the arc, being similar to doubly ionized lines in other rare-earth spectra. A few, however, appear at the positive pole of the arc, fading before they reach the central region; these are indicated in Table 1 by "E†." Their presence in the arc, sometimes in considerable strength, indicates that they arise from low levels of *Gd* III. They show decided red displacement as they approach the pole, resulting in inclined lines, difficult to measure. A mean wave

[3] *Sitzungsberichte Wien Akad.*, IIa, **125**, 1467, 1916.

[4] *Bureau of Standards Scientific Papers*, **18**, 695, 1923.

[5] *Mt. W. Contr.*, No. 414; *Ap. J.*, **72**, 221, 1930.

length is given, usually several hundredths of an angstrom smaller than the value in the M.I.T. list, which includes some of these lines. Such a difference would result if the M.I.T. measure is for the line close to the pole. Many strong lines of *Gd* II occur in the region λλ 2100–2700. Strong lines are found above λ 2400, which, on the basis of their weakness in the spark spectrum, appear to belong to *Gd* I, but may in some cases be low-level lines of *Gd* II.

λλ *2700–3900.*—This region contains many of the strongest lines of *Gd* II. Above λ 3000, most of these appear in the furnace spectrum. *Gd* I lines below λ 3900 are inconspicuous in a normally exposed arc spectrum, and few of them had been measured previously. While the furnace emission spectrum required high temperature, lines responding to lower excitation were brought out in the absorption spectrum. Strong spark lines are present, presumably belonging to *Gd* III; but, unlike some at shorter wave lengths, these did not appear in the arc spectrum.

λλ *3900–4700.*—In this section 627 lines, appearing on spectrograms of average strength, had been classified previously by the writer.[5] The present list for this region contains 1171 lines, an increase of 87 per cent. Intensities of lines previously classified have been changed to conform with intensities in the adjacent regions. Many *Gd* I lines appear, a considerable proportion being strong in the arc as well as in the furnace. Their number is comparable with that of *Gd* II. In the earlier work the identification of *Gd* II lines was confirmed by the quenching effect of caesium when mixed with gadolinium in the furnace.

λλ *4700–6700.*—Arc and spark spectrograms in the second order to λ 5400 were used for wave-length measurements and arc intensities, while first-order spectra furnished the fainter lines. The first order was used for the furnace spectrum. The outstanding lines belong to *Gd* I, and many are given much higher intensities in the furnace than in the arc. In the recent analysis of the spectral structure by Russell[6] almost all the lines placed in multiplets occur in this region. A large majority of those from the lowest level of *Gd* I (a^9D°) are given in Table 2 as relatively stronger in the furnace.

λλ *6700–11000.*—The use of infrared plates began at λ 6600. Low-temperature lines appear as far as λ 7750, beyond which the strong neutral lines are usually of class III. *Gd* II lines are more prominent than in the preceding region and include a large proportion of the stronger lines to λ 7400. At greater wave lengths, *Gd* II lines are infrequent, but exceptionally strong ones occur at λ 7846 and λ 7930.

In the infrared, as a result of disturbance by *CN* bands in the arc spectrum (silver electrodes containing *Gd* did not give a strong spectrum in this region), many intensities and some classes are uncertain; these are indicated by a question mark. The *Gd* lines were selected as far as possible by a direct comparison of the spectrum of the pure carbon arc with that of the arc containing *Gd*. As the 15-foot grating spectrum is weak beyond λ 9000, spectrograms for the arc and spark in this region were made with the 1-meter concave grating. These gave the lines in Table 3, for which only wave lengths and arc intensities are listed. As they did not appear in the spark spectrum, they belong presumably to *Gd* I.

Gd II LINES IN THE SOLAR SPECTRUM

Many strong *Gd* II lines are found in the spectral region open to astrophysical observation, a few of them having questioned identification with solar lines in the *Revised Rowland*. Using the data in Table 2 of the present paper, a search has been made for additional solar identifications. The strong *Gd* II lines between λ 3000 and λ 4500 often have considerable intensity in the furnace, and this evidence that they are from low atomic levels is confirmed by preliminary term analyses now available. Table 4 gives laboratory and solar data for these lines. Thirty-nine solar lines, some in blends, are identified with *Gd* II. The identifications of 9 are questioned, usually because the line is only moderately

[6] *Mt. W. Contr.*, No. 663; *Ap. J.*, **96**, 11, 1942.

strong in the arc; while 12, including some of the strongest arc lines, are masked in the sun. The largest differences between solar and arc wave lengths are found among the masked lines, the *Gd* II line, if present, evidently contributing only a small part to the blend. I am indebted to Mrs. Charlotte M. Sitterly for her co-operation in applying criteria for identification of solar lines.

From the analysis we find that 14 of the lines in Table 4 are from the low levels $a^{10}D^{\circ}$ and $a^{8}D^{\circ}$, being members of four multiplets found by Albertson, Bruynes, and Hanau;[7] while 17 other lines have transitions from these levels to miscellaneous higher ones not yet given term designations.[8]

For wave lengths greater than those in Table 4, strong *Gd* II lines are infrequent and are faint or absent in the furnace, hence presumably are from the higher levels. In this region the most probable solar identification is for λ 5733.86, the solar line being λ 5733.895, intensity −3.

EXPLANATION OF THE TABLES

The wave lengths in the first column are for the arc spectrum, except those followed by "(f)," which were measured in the furnace spectrum. This occurred usually when the arc line was a blend of *Gd* I and *Gd* II lines or was disturbed by a band absent in the furnace. The symbol "(b)" after the wave length indicates that the line may belong to a band. For the furnace, only the intensity at high temperature is given, the behavior at lower temperatures, including initial appearance and rate of strengthening with temperature, being considered in assigning the class in the final column. Classes I and II are made up of low-temperature lines, those of class I being more persistent. Lines appearing distinctly at 2300° are placed in class III, while those of class IV appear only at the highest temperature, and those of class V only in the arc. *Gd* II lines have "E" after the class number (in Table 1 after the arc intensity), with a dagger (†) if the strengthening in the spark is exceptional. Lines with the latter designation may belong to *Gd* III, especially those listed in Table 1. An asterisk (*) refers to a note at the end of the table.

[7] *Phys. Rev.*, **57**, 292, 1940.

[8] Albertson and Russell, unpublished.

TABLE 1

GADOLINIUM LINES FROM ARC AND SPARK SPECTRA PHOTOGRAPHED WITH QUARTZ SPECTROGRAPH
λλ 2134–2698

λ	Arc Int.	λ	Arc Int.	λ	Arc Int.
2134.67	5E	2241.28	3E?	2307.03	8E†
2141.10	50E	2242.32	8	2313.02	5
2143.35	60E	2243.42	8E	2318.83	15
2151.47	80E	2245.84	50E	2321.14	200E
2153.74	100E	2247.35	30E	2323.80	30E†
2155.75	5E	2248.06	6E?	2325.20	20E
2160.24	4E	2250.87	80E	2326.04	12E
2161.45	125E	2253.19	5E	2326.21	12
2163.39	6E	2254.62	15	2327.84	10E
2166.51	5E	2258.45	8E	2329.34	30E†
2167.57	500E	2261.09	3000E	2333.00	50E?
2168.37	2500E	2261.54	5E	2337.76	50E
2169.89	600E	2262.20	3E	2338.95	20E†
2170.69	2500E	2263.89	3E	2340.06	50
2175.35	4E?	2264.38	15	2351.58*	20?E?
2176.83	5E†	2266.51	15E	2353.63	30
2177.74	4000E	2268.62	10	2354.02	100?
2178.53	3000E	2270.76	50E	2358.85	12E
2179.69	600E	2272.55	15	2359.27	15E
2180.50	300E	2272.68	20	2359.93	40?
2181.05	4E?	2273.30	10E	2361.89	10E†
2185.75	5E?	2273.70	12E	2363.24	30E†
2186.66	10E	2274.02	5E?	2363.40	10?E?
2187.54	5E	2274.61	8E	2364.04	30
2191.03	3000E	2279.14	10E	2365.09	15
2191.84	5000E	2279.54	80E	2370.56	25
2192.87	6E	2279.79	300E	2374.49	8
2193.10	15E	2280.88	15	2375.93	12E
2196.45	60E	2281.03	10	2377.91	8
2198.07	10E	2281.73	2	2380.06	60E
2198.91	80E	2282.50	10	2380.30	150E
2200.73	30E	2282.75	8E?	2381.99	800E
2202.60	4E?	2283.60	25E	2382.42	10E?
2203.92	800E	2285.59	25	2382.99	60E?
2204.22	3E	2286.64	20	2385.96	6E?
2205.90	60E	2286.88	150E	2390.23	30
2215.94	15E	2288.84	10	2393.30*	40E?
2217.52	600E	2289.14	5E?	2393.64	5
2218.83	10E	2289.66	5E?	2396.41	40
2223.98	30E†	2290.86	40E	2396.83	5
2224.07	15E	2291.22	15	2399.63	20E
2225.80	10E	2291.50	8E?	2400.21	15
2227.33	6E	2291.83	5	2401.07	25E
2228.25	12E	2292.74	12	2403.27	50E
2228.46	10E	2292.95	8E	2405.51	25
2228.87	300E	2293.58	400E	2407.32	100
2229.51	30E	2293.90	10	2407.72	100E
2230.56	8E	2294.85	50E	2409.13	20E?
2231.41	10	2295.30	3E?	2410.11	60
2232.19	10	2295.67	8	2410.24*	100E?
2234.10	10	2296.09	4E?	2411.69	15E?
2234.59	6E	2296.58	6E?	2412.20	10E?
2234.92*	6E?	2297.26	40E?	2412.90	8E?
2237.07	4E	2299.09	40	2413.79	100
2237.40	20E	2302.04	5	2414.15*	10E?
2239.16	5E	2305.43	6	2416.16	5
2240.78	3E	2305.97	5E?	2416.54	30

TABLE 1—*Continued*

λ	Arc Int.	λ	Arc Int.	λ	Arc Int.
2417.67	40	2480.65	6E?	2553.17	15E
2418.32	25	2480.83	8E?	2553.93	300E†
2419.69	5	2481.16	10E	2554.08	100E†
2420.29	300	2481.62	40	2556.26	20
2421.79	15	2482.33	30E?	2556.37	10
2424.30	40E?	2483.00	5	2558.01	3
2424.61	200E	2483.77	15E?	2559.02	40E
2424.91	12	2485.67	1000E	2561.45	100
2425.09	30	2486.40	25E	2561.72	30E
2426.61	8E?	2487.01	20E	2562.48	2
2426.95	15	2487.46	2000E	2563.38	15E†
2428.07	25E	2488.72	2500E	2564.07	40E
2428.18	30E?	2490.01	100E	2564.47	500E†
2428.85	150	2490.41	5?E?	2564.71	4
2431.09	10E?	2490.82	2E	2565.18	30
2431.31	100E	2491.65	50E	2565.81	80E
2431.67	25?E?	2491.91	10E	2565.96	100E†
2432.25	8	2492.52	25E	2567.26	60E
2433.46	30?E?	2493.05	40	2567.51	40
2433.86	15	2493.29	600E	2568.18	12E
2434.44	40	2493.44	25E?	2569.01	10E
2434.66	200	2496.35	600E	2570.01	4
2437.82	30	2496.87	15E	2570.56	6E?
2439.05	50	2499.04	500E	2571.83	60
2439.69	30	2501.48	125	2572.28	15
2439.94	50?E?	2501.61	100E	2573.59	250E†
2441.67	300E	2502.46	15E	2574.03	200E
2443.49	250E	2502.62	10E?	2576.06	200E†
2444.40	10E†	2503.59	25	2576.95	10
2445.14	80	2504.63	20E?	2577.16*	100
2445.26	100	2504.83	200E	2578.19	4E?
2445.45*	80E?	2505.67	20E?	2578.69	20
2446.01	60E†	2506.61	80E	2579.03	80E
2447.81	200	2508.12	40E	2579.75	8E
2448.75	200E	2509.70	15	2580.26	8E
2449.98	100E	2512.96	15	2581.05	60E
2450.70	125E	2516.9	8d	2581.83	40
2452.66	15	2518.84	15E	2583.29	10E
2453.12	15	2519.59	50	2583.64	80E†
2457.15	10E	2520.47*	80E	2584.62	4
2458.47	15E	2522.35	60	2585.63	60
2461.30	5	2526.80	300E	2586.13	300E
2463.09	60	2531.66	50E	2588.07*	100E
2463.29	80	2531.75	100	2588.46	50E†
2464.96	6	2533.89	15	2590.25	40E
2465.32	20	2535.28	250	2591.17	40E
2466.87	30E†	2536.66	100	2594.13	50E
2468.22	5000E	2537.06	125	2596.62	4
2469.15	20E†	2537.82	80	2597.35	15E
2470.61	2E?	2538.40	100	2597.90	2
2471.58	2000E	2543.68	1000E	2599.43	2E?
2472.63	150	2546.55	100	2599.74	5E
2474.12	200E	2547.40	80E	2600.56	30
2474.25	100E	2547.61	125E	2601.04	30
2475.73	15E†	2550.18	800E	2602.32	2E
2477.27	200E	2551.30	200E	2603.92	50E
2477.62	50E	2551.58	150E†	2604.87	5E
2479.39*	15E?	2552.19	60E	2607.02	60
2480.02	4E	2552.76	3	2607.86	150E

TABLE 1—*Continued*

λ	Arc Int.	λ	Arc Int.	λ	Arc Int.
2608.52	20E	2629.18	15	2660.32	4E?
2608.67	40E?	2629.73	20E	2661.50	300E
2609.51	10E	2629.95	8E	2665.67	2E?
2609.82*	20E†	2630.44	25E	2666.09	4
2610.98	4E?	2631.69	50E	2667.24	30E
2611.49	30E	2632.44*	5E†	2667.77	4
2611.83	30dE	2633.17	25	2669.53	6E
2612.09	50	2633.36	30E	2670.91	5E
2612.55	30E	2634.95	4dE	2671.19	6
2612.81	6E	2635.20	2E	2672.71	2E
2613.18	4E	2636.01	1	2673.26	2E
2613.45	3E	2636.35	20E	2674.11	5E
2614.06	125	2637.80	1	2675.56	2E
2614.28	20E	2638.47	40	2675.77	3E†
2614.94	4	2639.53	4E	2676.55	2E
2615.66	40	2640.24	2E	2679.44	100E†
2616.88	20E?	2642.41	10E	2680.87	3E?
2617.25	12	2642.90	5E	2681.29	1
2618.51	15E	2643.21	5	2682.71	10
2619.07	10	2643.60	8E	2684.42	15
2619.79	3	2644.20	2	2685.67	8
2620.16	10E?	2645.83	4	2686.46	6E
2620.82	3E	2646.41	4E	2686.71	5
2621.74	15	2646.63	4	2687.10	2E
2622.87	40	2648.19	15	2688.21	30E
2623.53	5E†	2648.51	4	2689.57	2
2623.76	30	2648.73	2	2691.65	3
2624.46	15E	2649.27	3	2692.80*	40E
2624.94	20E?	2650.36	8	2693.27	3
2625.11	25	2651.59	2E	2695.12	2
2625.70	8	2651.93	2	2696.05	3
2626.52	50	2652.59	100E	2296.54	4
2626.77	10E	2653.01	3	2696.81	3E
2627.62	5	2655.04	25E	2697.43	1E
2628.12	300E†	2655.59	150E†	2697.79	8E
2628.28	3	2659.49	2	2698.44	5E

NOTES TO TABLE 1

λ		λ	
2234.92	Blend *Gd* III in spark	2520.47	Blend *Gd* I to red
2351.58	Blend spark line to red	2577.16	Blend *Eu*
2393.30	Blend *Gd* III in spark	2588.07	Blend *Gd* I to violet
2410.24	Blend *Gd* III in spark	2609.82	Blend *Gd* I to red
2414.15	Blend strong spark line	2632.44	Faint line to violet
2445.45	Blend *Gd* III in spark	2692.80	Blend *Gd* III in spark
2479.39	In wing of *C* λ 2478		

TABLE 2

TEMPERATURE CLASSIFICATION OF GADOLINIUM LINES
(λλ 2700–9081)

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2700.51	6	.....	V E	2736.90	2	.....	V E
2701.76	2	.....	V	2737.11	5	.....	V E ?
2702.21	1	.....	V E	2739.21	1	.....	V E
2705.360	50	.....	V E	2739.9	1–	.....	V E
2707.04	{2 1}	.....	V E	2740.17	8	.....	V E
				2740.38	2	.....	V E
2707.86	4	.....	V E	2740.635	10	.....	V E
2708.140	8	.....	V E	2740.78	6	.....	V
2709.125	1	.....	V E ?	2740.93	5	.....	V E
2709.532	6	.....	V	2741.22	1	.....	V E
2710.01	6d	.....	V E	2741.70	2	.....	V E
2710.37	3	.....	V E	2742.58	3	.....	V
2711.520	15	.....	V, V E	2743.35	20d	.....	V E
2712.03	3	.....	V E	2744.41	3	.....	V
2713.522	15	.....	V E	2744.477	25	.....	V
2713.915	40	.....	V E	2744.855	15	.....	V
2714.51	5	.....	V	2744.96	1	.....	V E
2714.90	2	.....	V E ?	2745.44	1	.....	V E
2715.630	12	.....	V E	2745.86	5	.....	V
2716.08	2	.....	V	2746.247	15	.....	V
2717.34	100	.....	V E †	2746.43	3	.....	V
2718.86	2	.....	V E	2747.147	20	.....	V E
2719.03	3	.....	V	2747.23	3	.....	V E
2720.16	5	.....	V	2747.545	25	.....	V E
2720.280	4	.....	V E	2747.74	3	.....	V
2720.497	200	.....	V E	2747.93	8	.....	V E
2721.40	10	.....	V E	2749.64	3	.....	V
2721.56	3	.....	V	2750.216	100	.....	V E
2723.16	8	.....	V E	2751.02	2	.....	V E
2724.35	1	.....	V E	2751.09	10	.....	V
2725.10	3	.....	V	2751.51	6	.....	V E
2725.53	6	.....	V	2751.58	3	.....	V E
2726.74	1	.....	V	2752.87	2	.....	V
2727.33	1	.....	V E	2752.94	10	.....	V E
2728.17	4	.....	V	2753.2	2	.....	V E †
2728.50	2	.....	V E	2753.82	3	.....	V E
2728.81	3	.....	V	2754.05	12	.....	V E †
2730.103	6	.....	V E	2754.81	4	.....	V
2730.446	3	.....	V E	2755.16	1	.....	V E
2730.56	4	.....	V	2755.40	1	.....	V E
2731.665	4	.....	V E	2755.508	20	.....	V
2732.67	4	.....	V E	2756.02	1	.....	V E ?
2733.115	8	.....	V	2756.36	2	.....	V
2733.25	2	.....	V	2756.709	5	.....	V E
2733.81	1	.....	V E	2757.20	2	.....	V E
2734.25	8	.....	V E	2757.34	1	.....	V E
2734.64	6	.....	V	2757.43	1	.....	V E
2735.11	3	.....	V E	2757.64	2	.....	V E
2735.63	3	.....	V E	2758.5	1–	.....	V E
2735.84	4	.....	V E	2759.421	15	.....	V
2735.97	2	.....	V E	2759.6	1	.....	V E
2736.22	1	.....	V E	2760.1	2	.....	V E
2736.5	1–	.....	V E	2760.750	12	.....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2760.9	2	.....	V E	2798.260	150	.....	V E
2761.22	2	.....	V E †	2799.40	4	.....	V E
2761.59	2	.....	V E	2799.63	2	.....	V E
2763.10	2	.....	V E	2799.818	20	.....	V
2763.8	1	.....	V E	2800.75	6	.....	V E
2764.076	3000	.....	V E	2801.68	3	.....	V E
2764.3	5?	.....	V	2803.43	1	.....	V E
2765.05	3	.....	V	2803.534	60	.....	V
2765.603	10	.....	V	2804.04	6	.....	V
2766.55	2	.....	V E	2805.69	3	.....	V E
2768.507	200	.....	V E	2806.261	100	.....	V
2768.9	2	.....	V E	2806.36	2	.....	V E
2769.808	1500	.....	V E	2806.51	2	.....	V E
2769.966	30?	.....	V	2806.837	30	.....	V E
2770.00	50?	.....	V	2808.380	150	.....	V E
2770.173	1200	.....	V E	2808.86	5	.....	V E
2770.23	50	.....	V E ?	2809.05	3	.....	V E
2770.503	20	.....	V E	2809.31	3	.....	V E
2770.983*	80d	.....	V E	2809.720	5000	.....	V E
2771.44	4	.....	V E	2810.18	5	.....	V
2772.44	4	.....	V E	2810.423	8	.....	V E
2773.28	6	.....	V E	2810.930	800	.....	V E
2774.087	80	.....	V	2811.293	60	.....	V
2775.100	80	.....	V	2811.94	4	.....	V
2775.69	8	.....	V E, V	2812.374	15	.....	V E
2778.39	3	.....	V E	2812.79	3	.....	V E
2778.760	125	.....	V	2813.429	15	.....	V E
2779.085	100	.....	V E	2814.011	150	.....	V E
2779.140	50	.....	V E	2814.71	6	.....	V
2779.407	15	.....	V E	2816.51	3	.....	V E
2780.754	3	.....	V E	2816.996	80	.....	V E
2781.29	60	.....	V E	2818.42	3	.....	V E
2781.402	3000	.....	V E	2819.19	2	.....	V E
2782.15	6	.....	V E	2820.623	20	.....	V
2782.206	50	.....	V E	2821.04	2	.....	V E
2784.00	3	.....	V	2821.34	4	.....	V E
2784.52	4	.....	V E	2821.73	1	.....	V
2784.782	12	.....	V E	2821.83	3	.....	V
2786.56	4	.....	V	2822.71	10	.....	V
2786.71	4	.....	V E	2823.27	1	.....	V E
2786.854	100	.....	V	2823.528	4	.....	V
2787.677	250	.....	V	2824.394	40	.....	V
2788.21	3	.....	V E	2824.702	6	.....	V E
2789.920	20	.....	V E	2825.20	2	.....	V E
2790.300	80	.....	V E	2826.03	3	.....	V E
2790.644	50	.....	V E	2826.19	4	.....	V E
2791.963	1500	.....	V E	2827.18	5	.....	V
2792.07	50	.....	V E	2827.36	2	.....	V
2792.640	15	.....	V E	2827.938	80	.....	V
2792.80	2	.....	V E	2828.634	60	.....	V
2793.211	40	.....	V E	2828.99	4	.....	V E
2794.353	30	.....	V	2829.22	2	.....	V E
2794.565	80	.....	V	2830.52	1	.....	V E
2794.661	100	.....	V E	2830.69	3	.....	V
2796.667	30	.....	V E	2830.76	3	.....	V
2796.932	6000	.....	V E	2832.44	8	.....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2833.072	30?		V E	2864.091	10		V E
2833.746	1500		V E	2865.063	500		V E
2833.85	40?		V E†	2865.48	3		V E
2835.104	50		V	2866.334	125		V E
2835.86	4		V E	2866.458	80		V E
2836.47	20		V E	2868.008	40		V E
2836.688	200		V E	2868.19	8		V E
2836.996	500		V E	2868.535	20		V E
2837.18	6		V E	2868.959	20		V
2838.11	20		V E	2869.797	25d?		V E ?
2838.58	2		V E	2869.995	50		V E
2838.77	5		V	2870.454	40		V
2838.89	2		V E	2871.16	2		V E
2839.550	25		V E	2871.42	3		V E
2839.74	6		V	2871.754	200		V E
2839.97	12		V E	2872.28	5		V E
2840.231	3000		V E	2873.086	100		V
2841.329	600		V E	2874.32	6		V E
2842.800	15		V E	2875.00	8		V E
2842.95	12		V	2875.10	6		V E
2844.265	15		V	2875.14	4		V E
2844.533	100d?		V	2875.460	50		V E
2845.44	12		V E	2875.558	15		V
2845.957	40		V	2876.515	30		V
2846.14	3		V	2877.02*	20?		V E
2846.44	5		V E	2877.063	100		V E
2847.42	5		V E	2877.26	2		V E
2847.75	10		V E	2877.49	2		V E
2847.86	80		V E	2878.03	3		V E
2848.16	8		V	2878.56	3		V E
2848.90	5		V E	2879.09	12		V
2849.48	8d?		V	2881.00	3		V E
2850.44	3		V E	2881.329*	4000		V E
2850.627	20d?		V	2881.93	4		V
2851.98	150		V	2882.130	150		V E
2852.28	100		V	2882.257	50		V E
2853.398	20		V	2882.683	25		V E
2853.914	150		V E	2884.43	8		V
2854.26	20		V E	2884.56	3		V E
2854.84	2		V E	2885.02	12		V E
2855.418	30		V E	2885.336	15		V
2855.91	4		V E	2885.41	5		V E
2856.520	300		V E	2885.596	600		V E
2856.89	4		V E	2886.30	4		V E
2857.20	2		V E	2886.77	8		V E
2857.811	100		V E	2886.88	5		V E
2858.877	50		V E	2887.507	100		V
2859.09	3		V E	2888.18	80		V E
2859.776	150		V E	2888.72	4		V
2860.670	50		V E	2888.83	4		V
2860.92	3		V E	2889.11	10		V E
2861.07	6		V E	2889.21	10		V E
2861.50	5		V	2889.83	3		V E
2862.475	800		V E	2890.530	200		V E
2863.682	80		V	2890.805	20		V E
2863.97	2		V E	2890.913	50		V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2891.69	4	.....	V E	2918.517	200	.....	V E
2892.084*	300	10	II	2918.782	50	.....	V
2893.464	30	.....	V	2919.306	30	.....	V
2893.60	5	.....	V E	2919.440	25	.....	V
2894.290	125	.....	V E	2920.223	10	.....	V
2894.44	6	.....	V E	2920.331	8	.....	V
2895.237	200	.....	V E	2921.18	2	.....	V E
2895.528	300	.....	V E	2921.60	15	.....	V E
2896.01	8	.....	V E	2922.46	.5	.....	V E
2896.42	6	.....	V E	2923.322	800	.....	V E
2897.024	80	.....	V	2923.835	4	.....	V E
2897.45	3d?	.....	V E	2924.254	200	.....	V E
2897.564	10	.....	V E	2925.121	30	.....	V E
2898.00	1	.....	V E	2925.864	15	.....	V E
2898.200	6	.....	V E	2927.398*	150	10	II
2898.515	6	.....	V E	2927.851	10	.....	V E
2899.032	125	.....	V	2928.015	1	.....	V E
2899.218	60	.....	V E	2928.336	300	.....	V E
2899.48	2	.....	V E	2928.705	80	.....	V E
2899.77	1	.....	V E	2928.87	2	.....	V
2900.20	8	.....	V E	2929.095	200	.....	V E
2900.565	80	.....	V	2930.67	8	.....	V E
2901.28	4	.....	V	2931.06	15	.....	V E
2902.091	15	.....	V E	2931.41	30	.....	V
2902.22	2	.....	V E	2931.56	5	.....	V E
2902.82	5	.....	V E	2932.76	5	.....	V E
2903.752*	200	10	II	2932.927	100	.....	V E
2903.94	4	.....	V E	2933.794	200	.....	V
2904.41	4	.....	V E	2934.40	4	.....	V E
2904.548	40	.....	V E	2935.025	60	.....	V
2904.600*	60	5?	III	2935.23	4	.....	V
2904.79	10	.....	V E	2935.336	15	.....	V E
2905.307	4000	.....	V E	2935.717	12	.....	V E
2905.973	80	.....	V E	2936.147	12	.....	V
2906.260	125	.....	V E	2936.540	40	.....	V E
2907.17	5	.....	V	2936.631	8	.....	V
2907.437	80	.....	V E	2937.294	20	.....	V E
2908.875	50	.....	V E	2937.56	6	.....	V E
2909.18	2	.....	V E	2937.892	10	.....	V E
2909.28	4	.....	V E	2938.49	4	.....	V E
2910.526	1500	.....	V E	2938.59	2	.....	V E †
2910.84	4	.....	V E	2939.68	4	.....	V E
2911.13	2	.....	V E	2939.92	6	.....	V E
2912.64	2	.....	V E	2940.16	2	.....	V
2913.080	300	.....	V E	2940.854	25	.....	V E
2913.69	3	.....	V E	2941.064	4	.....	V E
2914.03	6	.....	V E	2941.30	30	.....	V E
2914.252	60	.....	V	2941.43	15	.....	V
2914.824	40	.....	V E	2941.635	100	.....	V
2915.477	8	.....	V E	2942.00	8	.....	V
2916.19	4	.....	V E	2942.330	15	.....	V E
2916.294	15	.....	V E	2942.83	3	.....	V
2917.36	4	.....	V E	2944.00	30	.....	V
2917.72	10	.....	V E	2944.482	80	.....	V
2917.87	12	.....	V E	2944.76	2	.....	V E
2918.29	8	.....	V E	2945.574*	250	6	II

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
2945.691	80		V E	2969.90	2		V E
2946.13	60		V	2969.98	2		V
2946.32	2		V E	2970.350	20		V
2947.19	10		V E	2970.850	25		V E
2947.25	8		V	2971.23	2		V
2947.481	30		V E	2971.52	4		V E
2947.54	15		V	2971.56	4		V E
2947.60	30		V	2972.17	100		V E
2947.795	200		V E	2972.742	150		V E
2948.01	250		V E	2973.02	4		V E
2948.06	10?		V E	2973.33	5		V E
2948.25	4		V	2973.647	100		V E
2948.91	8		V E	2974.19	3		V E
2949.63	6		V	2974.822	15		V
2949.991	20		V E	2975.110	30		V E
2951.278	25		V E	2975.62	3		V
2952.43*	250	5	III	2976.12	6		V E
2952.81	40		V	2977.335	25d?		V E
2953.02	3		V E	2977.586	12		V E
2954.02	25		V E	2977.884	20		V E
2954.404	10		V	2978.08	4		V
2954.538	30		V E	2978.554	100		V E
2955.402	60		V E	2979.25	3		V E
2955.595	200		V E	2979.57	3		V E
2955.70	4		V E	2979.76	4		V E
2955.90	4d?		V E	2980.154	6000		V E
2956.13	8		V	2980.22	10?		V E ?
2956.34*	12	5	III	2980.962	15		V
2956.73	5		V E	2981.208	125		V E
2957.19	3		V E	2981.70	5		V E
2957.69	12		V E	2982.554	100		V
2958.05	8		V	2983.060	60		V E
2959.225	60		V E	2983.37	10		V
2959.53	4		V E	2983.745	200		V E
2959.86	6		V	2984.13	3		V
2960.80	15		V	2984.192	30		V E
2960.926	500		V E	2984.37	3		V E
2962.252	30		V E	2984.45	8		V E
2963.00	6		V E	2985.06	5		V E
2963.525	200		V E	2985.521	100		V E
2963.605	400		V E	2985.80	8		V E
2963.96*	15		V	2986.60	5		V
2964.28	5		V E	2987.074	80		V E
2964.608	20		V E	2987.850	20		V
2965.17	3		V E	2988.196	15		V
2965.26	5		V E	2988.532	100		V E
2965.428	400		V E	2988.76	10		V
2965.583	6		V E	2988.903	60		V E
2966.083	5		V	2988.98	4		V E
2966.424	80		V	2989.11	5		V
2966.631	50		V E	2989.52	2		V E
2968.10	6		V	2990.45	40d		V
2968.29	4		V E	2990.530	60		V E
2968.94	20		V	2991.054	60		V E
2969.21	10?		V	2991.520	150		V E
2969.267	50		V E	2991.798	20		V

TABLE 2—*Continued*

λ	Intensity		Class
	Arc	Furnace	
2991.968	5	.....	V E
2992.10	4	.....	V E
2992.28	4	.....	V E
2992.43	3	.....	V
2992.60	4	.....	V
2993.038	500	.....	V E
2993.696	15	.....	V E
2994.240	20	.....	V E
2994.855	20	.....	V E
2997.365	60	.....	V
2998.08	2	.....	V E
2999.045	8000	.....	V E
2999.51	1	.....	V E
3000.36	3	.....	V
3000.71	3	.....	V E
3000.79	3	.....	V E
3000.86	5	.....	V E
3002.197	50	.....	V E
3002.449	50	.....	V E
3002.710	60	.....	V E
3002.860	1000	.....	V E
3003.583	150	.....	V E
3004.163	5d	.....	V
3004.83	10	.....	V E
3005.092	300	.....	V E
3005.18	4d	.....	V E
3005.393	5	.....	V E
3005.900	6	.....	V
3006.397	4	.....	V
3007.10*	10	.....	V E
3007.49	2	.....	V
3008.760	10	.....	V E
3008.995	15	.....	V
3009.366	60	.....	V E
3009.418	20	10	II
3009.650	150	.....	V E
3009.936	30	.....	V
3010.129*	8000	5	IV E
3010.526	50	.....	V E
3010.899	250	.....	V E
3011.23	5	.....	V
3011.94	8	.....	V
3012.190	600	.....	V E
3012.584	8	.....	V E
3013.22	6	.....	V E
3013.74	2	.....	V
3013.89	5	.....	V E
3015.115	6	.....	V
3016.365	40	.....	V E
3017.116	4	.....	V E
3017.734	2	.....	V
3017.81	6	.....	V E
3020.19	4	.....	V E
3020.23	2	.....	V E
3022.104	150	.....	V E
3022.394	5	.....	V E
3023.838	10	.....	V
3024.04	50	.....	V E
3025.35	3	.....	V
3025.83	15	.....	V E
3026.207	20	.....	V
3026.96	3	.....	V E
3027.602	8000	.....	V E
3028.981	200	.....	V E
3029.885	6	.....	V
3030.00	2	.....	V E
3030.441	10	.....	V E
3030.652	150	.....	V E
3030.91	5	.....	V E
3030.972	10	.....	V E
3031.914	50	.....	V E
3032.313	12	.....	V E
3032.58	3	.....	V
3032.845	10000	10	IV E
3034.051	8000	10	IV E
3034.39	8	.....	V E
3034.69	4	.....	V E
3035.36	2	.....	V E †
3036.75	1	.....	V E †
3037.05	2	.....	V E
3037.140	10	.....	V E
3037.39	8	.....	V E
3038.33	15d	.....	V E
3038.91	5	.....	V
3038.97	5	.....	V E
3039.60	2	.....	V E
3039.74	5	.....	V
3039.79	5	.....	V E
3040.34	150	.....	V E
3040.94	25	.....	V E
3041.61	6	.....	V E
3043.008	80	40	I
3043.10	30	.....	V E
3044.744	5	.....	V E
3046.482	125	60	I
3048.62	15	.....	V
3049.483	20	.....	V E
3049.96	3	.....	V E
3050.76	4	.....	V
3052.511	50	.....	V E
3053.570	600	.....	V E
3054.430	15	.....	V E
3054.555	15	.....	V E
3055.17	4	.....	V E
3055.497	20	.....	V E
3056.807	25	.....	V E
3057.183	20	.....	V E
3057.395	50	20	II
3057.594	6	.....	V E
3057.970	80	.....	V E
3058.119	80	.....	V E
3058.28	4	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3058.86	8	.....	V E	3091.63	3	4	III
3059.555	8	.....	V E	3091.863	40	.....	V E
3059.916	100	40	I	3092.058	150	.....	V E
3060.463	20	.....	V E	3093.62	5	.....	V E
3061.947	40	.....	V E	3093.846	25	.....	V E
3062.423	15	.....	V E	3095.084	8	.....	V E
3063.536	10	.....	V E	3095.778	15	.....	V E
3063.702	10	.....	V E	3096.212	50	.....	V E
3064.327	20	.....	V E	3096.53	10	.....	V
3064.733	15	.....	V E	3096.802	50	.....	V E
3064.965	10	.....	V	3097.75	6	3	III
3066.38	1	.....	V E †	3097.82	10	.....	V E
3066.41	20	.....	V E †	3098.644	800	.....	V E
3066.603	30d?	.....	V E	3098.899	300	.....	V E
3067.286	20	.....	V E	3099.53	8	.....	V E
3067.619	40	.....	V E	3100.504	10000	30	IV E
3067.665	10?	.....	V E ?	3101.185	125	.....	V E
3067.755	15	.....	V	3101.407	50	.....	V E
3068.643	4000	3	IV E	3101.608	20	20	II
3069.225	20	.....	V E	3101.786	15	.....	V E
3069.419	40	50	I	3101.911	250d	.....	V E
3069.517	8	5	III	3102.551	1000	.....	V E
3069.623	4	.....	V E	3102.838	15	.....	V E
3070.395	5	.....	V E ?	3103.141	10	.....	V E
3072.565	1000	.....	V E	3105.533	80	.....	V E
3072.963	20	.....	V E	3107.69	5	5	III
3075.422	30	.....	V E	3108.230	30	.....	V E
3076.188	10	.....	V E	3108.360	150	.....	V E
3076.925	2000	.....	V E	3109.505	20	.....	V E
3077.077	800	.....	V E	3109.948	12	.....	V E
3078.108	6	.....	V E	3110.566	5	.....	V
3080.128	12	5	III	3111.187	80	60	I
3080.950	30	40	II	3111.995	20	.....	V E
3081.31	5	.....	V E	3112.330	4	6	III
3081.993	8000	15	IV E	3112.472	5	.....	V E
3082.35	4	.....	V	3112.684	10	.....	V E
3083.350	200	.....	V E	3113.172	250	.....	V E
3084.007	250	.....	V E	3113.64	4	.....	V E
3084.744	10	.....	V E	3114.05	3	.....	V E
3085.055	125	.....	V E	3115.77	10	.....	V E
3085.478	20	.....	V E	3117.011	15	.....	V E
3085.621	60	.....	V E	3117.974	40	.....	V E
3085.74	4	.....	V E	3118.600	150	.....	V E
3086.051	6	.....	V E †	3119.013	60	50	II
3086.234	50	.....	V E	3119.08	60	.....	V E
3087.049	40	40	II	3119.336	25	.....	V E
3088.943	8	.....	V E	3119.59*	3	.....	V
3089.204	30	.....	V E	3119.941	800	.....	V E
3089.252	20	.....	V E	3120.181	125	.....	V E
3089.59*	6	.....	V E	3120.748	8	.....	V E
3089.85	15	.....	V E	3121.11	2	2	III
3089.954	400	5	IV E	3121.27	10	.....	V E †
3090.384	30	40	II	3121.59	8	.....	V E
3090.579	60	.....	V E	3121.760	80	.....	V E
3090.754	12	.....	V E	3123.391	6	.....	V E
3091.463	8	.....	V E	3123.694	100	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3123.989	1000	.....	V E	3151.915	20	.....	V E
3124.096	10?	.....	V	3152.146	4	.....	V E
3124.250	150	.....	V E	3153.916	25	.....	V E
3124.57	15	.....	V E	3154.28	5	5	III
3124.81	3	.....	V E	3155.937	5	.....	V E
3124.905	40	60	I	3156.274	8	12	III
3125.51	5d	.....	V	3156.532	2000	4	IV E
3126.65	4d	.....	V E	3156.72	10	.....	V E
3126.930	6	.....	V E	3157.15	2	.....	V E †
3127.246	40	40	II	3157.361	10	.....	V E
3127.696	100	.....	V E	3157.785	6	.....	V E
3128.36	4	.....	V E	3158.247	5	10	III
3128.560	200	.....	V E	3158.629	125	100	I
3129.696	80	.....	V E	3159.224	15?	25	III
3129.955	100	.....	V E	3160.0	1	.....	V E †
3130.19	4	.....	V E	3160.410	15	20	III
3130.386	50	.....	V E	3160.69	200	.....	V E
3130.513	3	.....	V	3160.730(f)		40	II
3130.812	200	.....	V E	3160.86	3	.....	V E
3131.765	10	.....	V E	3161.369	2500	2	IV E
3132.34	15	.....	V E	3161.638	40	.....	V E
3132.405	40	40	II	3162.764	25	.....	V E
3133.094	150	.....	V E	3163.071	4	.....	V E
3133.852	1000	.....	V E	3163.32	3d	.....	V E
3134.765	2	.....	V	3163.535	10	.....	V E
3135.034	200	.....	V E	3164.05	2	.....	V
3135.151	30	40	II	3165.046	25	30	II
3135.283	20	.....	V E	3166.10	5	.....	V E
3135.878	15	.....	V E	3166.34	4	.....	V E
3135.947	4	.....	V	3166.896	10	.....	V E
3136.926	100	80	I	3167.203	30	30	II
3137.303	125	80	I	3167.529	4	.....	V E
3137.940	80	.....	V E	3168.127	50	.....	V E
3138.094	80	.....	V E	3168.291	60	.....	V E
3138.707	60	40	II	3168.52	1	.....	V E
3139.166	30	30	II	3169.470	80	.....	V E
3139.725	15	.....	V E	3169.584	10	2	III
3140.59	2	.....	V E	3170.81	3	5	III
3140.66	3	.....	V E	3171.09	125	.....	V E
3140.797	80	.....	V E	3171.35	3	.....	V E
3142.163	6	.....	V	3172.169	30	.....	V E
3142.217	5	.....	V E	3172.623	5	.....	V E
3142.900	300	.....	V E	3172.868	40	.....	V E
3143.131	400	.....	V E	3174.117	30	.....	V E
3145.00	2500	2	IV E	3174.34	2	.....	V E
3145.124	40	50	II	3174.502	15	.....	V E
3145.516	800	.....	V E	3174.960	40	50	II
3145.621	10?	.....	V E	3175.04	4	.....	V E
3146.805	10?	.....	V	3175.310	6	.....	V E
3146.878	250	.....	V E	3175.65	2	.....	V
3147.83	4	.....	V E	3176.32	4	.....	V E
3147.94	3	.....	V	3177.03	4	6	III
3148.76	15	.....	V E	3177.490	30	.....	V E
3149.19	2	.....	V E	3177.566	15	.....	V
3149.770	15	20	III	3177.84	4	.....	V E
3151.522	3	.....	V	3178.60	6	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3178.943	12		V E	3210.34	2		V E
3179.600	5		V E	3211.07	2		V E
3180.034	10		V, V E	3211.237	4		V
3180.26	3		V E	3211.570	50		V E
3180.86	4		V E	3211.795	8		V E
3181.184	8		V E	3212.274	50		V E
3181.65	6		V E	3212.36	1		V E
3182.548	60		V E	3212.538	10		V E
3182.90	3		V E	3212.884	20		V E
3183.583	8		V E	3213.999	20		V E
3185.230	6		V E	3215.260	1000	500	I
3185.379	5		V E	3216.397	6		V E
3186.425	15		V E	3217.035	25		V E
3186.654	25	5	III	3217.127	40		V E
3187.114	100		V E	3217.720	3		V
3187.795	12		V E	3218.107	10		V
3188.387	12		V E	3218.397	30	40	III
3189.840	20		V E	3218.645	8		V E
3190.280	200	150	I	3219.250	15		V E
3190.46	3		V E	3219.7	1		V E †
3191.044	125		V E	3219.98*	8		V
3191.283	6	15	III A	3220.459	8		V E
3191.623	15		V E	3220.672	6		V E
3192.486	3	5	III	3222.670	50	60	III
3192.608	3		V E	3223.26	6		V
3193.174	200		V E	3223.534	6		V E
3193.913	6		V	3223.740	1000?		V E
3194.058	5		V	3223.785	2000?	800	I
3195.160	6		V	3224.18	3		V E
3195.736	25		V	3224.297	60		V E
3196.532	150		V E	3225.460	600		V E
3196.708	6		V	3226.318	1000		V E
3197.39	3		V	3226.769	3		V E
3198.72	5		V	3227.361	6		V E
3199.303	200	150	II	3227.614	6		V E
3199.585	150	100	II	3227.82	2		V E
3199.814	6		V E	3228.48	3		V E
3200.312	50		V E	3228.641	15		V E
3200.454	60		V E	3229.142	4		V E
3200.89	2		V	3229.323	25		V E
3201.019	30		V	3230.71	2		V
3201.366	4	8	III A	3230.83	1		V E †
3201.94	4	4	III	3232.395	40		V
3202.192	6		V E	3232.696	50		V E
3202.845	6	3	III	3232.779	80	200	II A
3202.897	8	10	III	3232.948	80		V E
3203.413	50	80	II	3233.145	100	200	II A
3205.868	8		V E	3233.467	6		V E
3205.96	2		V E	3234.05	3		V E
3206.104	8		V E	3234.28	3	6	III A
3206.466	400		V E	3234.87	6		V E
3207.57	3		V E	3234.93	2		V E
3207.738	150		V E	3235.213	3		V E
3208.998	5		V E	3236.106	150		V E
3209.660	60		V E	3236.72	2		V E
3209.817	6		V E	3237.234	80	150	II A

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3237.617	100	.....	V E	3267.643	200	300	II
3238.27	4	.....	V E	3267.880	12	.....	V E
3238.621	300	.....	V E	3268.20	5	.....	V E
3238.870	80	100	II	3268.335	400	.....	V E
3239.49	4	8	III A	3268.748	4	.....	V E
3239.88	2	.....	V E	3268.90	1	.....	V E
3240.727	40	40	III	3270.084	4	.....	V E
3241.127	200	250	II	3270.515	100	.....	V E
3242.304	150	.....	V E	3271.51	1	.....	V E
3242.834	50	.....	V E	3271.750	200	400	II A
3243.68	2	.....	V E	3272.00	2	.....	V E
3244.182	8	.....	V E	3272.26	3	.....	V
3244.826	20	80	III A	3273.03	2	.....	V
3244.93	3	.....	V E	3273.157	12	.....	V E
3245.74	4	.....	V E	3273.31	2	.....	V E †
3246.099	25	.....	V E	3274.183	300	.....	V E
3246.272	30	100	III A	3275.072	5	.....	V E
3247.022	5	.....	V E	3275.205	20	.....	V E
3247.45	4?	.....	V E	3275.260	20	.....	V E
3248.044	100	250	II A	3275.996	4	.....	V
3248.462	25	.....	V E	3276.37	3	.....	V E
3249.747	40	.....	V E	3276.92	4	5	III
3250.187	300	.....	V E	3277.05	2	.....	V E
3251.329	8	.....	V E	3277.516	80	100	III
3251.495	4	10	III A	3278.038	12	.....	V E
3252.743	30	.....	V E	3278.7	1	.....	V E †
3253.614	15	.....	V E	3279.529	200	.....	V E
3255.276	6d	.....	V E	3279.918	250	500	II A
3255.819	150	.....	V E	3280.469	10	.....	V E
3256.135	3	.....	V E	3281.607	200	.....	V E
3256.34*	10?	.....	V E	3282.254	200?	400	II A
3256.377	80	.....	V E	3282.305	400?	.....	V E
3256.423	1	.....	V E †	3283.281	8d?	.....	V E
3256.932	150	300	II A	3283.441	4	3	IV, V E
3257.072	100	.....	V E	3284.11	4	.....	V E
3257.93	2	.....	V	3285.606	12	6	IV
3257.98	2	.....	V E	3286.15	1	.....	V E
3258.77	1	3	III A	3287.192	40	.....	V E
3259.250	250	.....	V E	3287.44	1	.....	V E
3259.66	6	3	III	3288.165	20	.....	V
3259.940	200	250	II	3288.692	6	.....	V E
3260.59	3	.....	V E	3289.105	10?	30	III A
3260.74	2	.....	V E	3289.150	100	.....	V E
3261.619	4	.....	V E †	3289.485	8	.....	V E
3261.967	6	.....	V E	3290.37	2	.....	V E
3262.330	6	.....	V E	3291.008	6	.....	V E
3262.515	80	.....	V E	3291.07	1	.....	V E
3262.774	8	.....	V E	3291.484	200	600	II A
3263.373	125	.....	V E	3292.210	800	.....	V E
3264.137	60	.....	V E	3294.080	200	500	II A
3264.46	4	.....	V E	3294.90	2	.....	V
3265.54	2	.....	V	3295.289	5d?	.....	V
3266.06	1	.....	V E	3296.668	30	.....	V E
3266.15	3	.....	V E	3296.782	6	.....	V E
3266.726	300	500	II	3297.7	1	.....	V E
3267.080	10	.....	V E	3298.518	100	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3298.688	4	1	IV	3322.99	3		V E
3298.945	5		V E †	3323.987	10	25	III A
3299.07	2		V	3324.86	4		V E †
3299.12	2		V E	3325.70	3		V
3299.28	8		V E	3325.842	25	60	III A
3299.50	2	1	IV	3325.926	3		V E
3300.922	4		V ?	3327.02	2		V E
3300.976	60		V E	3327.13	2		V E
3302.152	10		V E	3327.402	1		V
3302.195	10		V E	3327.610	1		V E †
3302.584	6		V	3327.752	8		V E
3302.865	6		V E	3327.886	10		V E
3303.623	5		V E	3328.615	3		V E
3304.105	4		V	3328.690	2		V
3304.442	15		V E	3329.345	400		V E
3304.88	6		V E	3329.75	1		V E
3305.010	6		V E	3330.340	800		V E
3305.399	8		V E	3330.455	10		V E
3306.38	2		V E	3331.383	4000	30	IV E
3306.443	4	3	IV	3332.133	1000		V E
3307.101	3		V E	3332.71	6		V E
3307.72	2		V E	3333.209	40		V E
3308.517	80		V E	3334.064	150		V E
3309.349	4		V E	3334.75	5	3	IV
3309.51	3	2	IV	3335.823	6d?		V E
3309.582	60		V E	3336.180	2500	20	IV E
3310.924	8		V	3336.984	200		V E
3311.384	6	4	IV	3337.065	5		V E
3311.570	5		V E	3339.30	3		V E
3312.553	8	25	IV A	3339.49	2		V E
3313.17	1		V E	3340.14	15		V E
3313.370	80		V E	3340.782	5	8	IV
3313.731	600		V E	3341.166	6		V E
3313.95	2	2	IV	3342.083	4		V E
3314.148	5		V E †	3344.22	1		V E
3314.34	2		V E	3344.75	1		V ?
3315.06	2		V E	3344.944	1		V
3315.590	400		V E	3345.412	100		V E
3316.342	100		V E	3345.585	2		V E
3316.558	200		V E	3345.825	80		V E
3316.791	4		V E	3345.925	?	15	III
3316.866	4		V E	3345.985	2000	6	IV E
3317.254	200	600	II A	3346.74	3		V E †
3317.813	2		V E	3347.095	2		V
3318.055	100		V E	3348.718	5		V E
3318.465	3		V	3348.938	3		V
3319.15	4d?		V E	3350.097	400		V E
3319.702	12	8	IV	3350.474	10000	150	IV E
3319.833	15		V E	3350.788	10	80	III A
3320.317	20		V E	3351.908	4		V E
3320.438	300		V E	3352.271	3		V E †
3321.348	30		V E	3352.512	40		V E
3321.459	2		V E	3353.869	15		V E
3321.744	15		V E	3353.992	3		V E
3321.92	1		V E †	3354.114	2		V
3322.144	20	80	III A	3354.920	25		V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3355.21	2		V	3380.515	300		V E
3355.28	2		V	3380.781	4		V E
3355.39	3		V E	3381.513	10		V E
3355.52	4		V E	3381.786	40		V E
3355.67	1		V	3382.01	2	3	IV
3356.289	2		V	3382.228	60	100	II
3356.513	80		V E	3382.43	4d?		V
3357.612	100	250	II A	3383.288	10		V E
3358.434	300		V E	3383.683	20		V E †
3358.620	8000	150	IV E	3384.27	3		V
3358.872	6		V E	3385.307	30		V E
3359.74	2		V E	3385.425	4		V E †
3360.178	2		V E †	3385.745	4		V E
3360.711	1000	12	IV E	3386.312	2		V E †
3361.724	60	150	II A	3386.470	6		V
3362.233	10000	150	IV E	3387.511	4		V E
3362.938	125		V E	3388.065	40		V E
3363.241	8		V E	3388.614	50	200	II A
3363.974	30		V E	3388.912	100		V E
3364.085	2	15	IV A	3389.336	3		V E
3364.241	500		V E	3389.53	1		V
3364.85	3		V E	3390.498	30		V E
3364.98	1	10	IV A	3390.878	200		V E
3365.591	400		V E	3391.074	20		V E
3366.532	50		V E	3391.294	150		V E
3366.755	6		V E †	3392.007	25		V E
3367.004	4		V	3392.530	2000	25	IV E
3367.093	100		V E	3392.743	20	100	III A
3367.383	5		V E	3393.069	30		V E
3367.661	150		V E	3393.630	400		V E
3367.8	2		V E †	3394.151	40		V E
3367.984	5		V E	3394.4	1		V E †
3369.618	400		V E	3395.120	1000		V E
3370.402	60	100	II	3395.552	5		V E
3370.74	1		V E	3396.300	4		V E
3371.15	20?	5	IV	3396.481	2		V E †
3371.381	5	40	II A	3396.784	20		V E
3371.506	4		V E	3397.220	80	300	II A
3372.17	2		V	3397.324	60	250	II A
3372.869	1		V E †	3398.304	8	8	IV
3373.02	1		V	3398.516	20	80	III A
3373.38	4		V E †	3398.91	2		V E
3373.844	100	200	II A	3399.150	12		V E
3373.95	2	5	IV	3399.406	500		V E
3374.584	50		V E	3399.991	1200	4	IV E
3374.688	300		V E	3400.886	8		V E
3375.135	2	12	IV A	3401.067	300		V E
3376.64	2		V E	3401.675	2		V E
3376.946	3		V	3402.072	1000		V E
3377.50	4		V	3403.081	150		V E
3378.61	2		V	3403.206	15		V E
3378.89	3		V E	3403.336	40		V E
3378.944	3		V E	3403.70	2		V E
3379.756	400		V E	3405.038	150		V E
3379.87	2		V	3405.57	2	4	IV A
3380.007	200		V E	3406.692	3	2	V E †, IV

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3406.915	100	400	II A	3431.500	40	.....	V E
3407.56	600?	.....	V E	3432.394	3	25	III A
3407.61	1500?	3	IV E	3432.994	1500	10	IV E
3408.23	2	.....	V E	3433.41	2	.....	V E
3408.466	3	.....	V	3433.730	10	.....	V E
3408.615	20	.....	V E	3434.011	4	.....	V E
3408.667	5	.....	V E	3434.17	2	.....	V E
3409.297	500	.....	V E	3434.41	2	.....	V E †
3410.131	5	.....	V	3434.626	8	.....	V E
3410.181	6	.....	V E †	3435.643	5	40	III A
3410.445	5	.....	V E †	3435.982	12	100	III A
3411.016	80	250	II A	3436.050	3	.....	V E †
3411.268	10	.....	V E	3436.63	1	8	IV A
3411.570	50	.....	V E	3437.242	3	.....	V E ?
3412.020	200	.....	V E	3437.843	10	.....	V E
3412.583	60	.....	V E	3437.966	8	.....	V E
3412.753	80	.....	V E	3438.909	4	.....	V
3413.273	400	.....	V E	3439.069	20?	.....	V
3413.563	5	60	III A	3439.208	3000	20	IV E
3414.207	60	.....	V E	3439.784	1500	10	IV E
3415.260	6	6	IV, V E	3439.990	6000	60	IV E
3415.471	8	.....	V E	3440.268	40	.....	V E
3416.948	2500	10	IV E	3440.61	3	3	IV
3417.330	150	.....	V E	3441.790	400	.....	V E
3418.405	3	.....	V	3442.88	3	.....	V E
3418.621	40?	150	II A	3443.08	2	.....	V E †
3418.733	2000	30	IV E	3443.48	2	.....	V E
3418.930	20	.....	V E	3443.54	2	.....	V E
3419.069	50	.....	V E	3443.796	5	.....	V
3420.714	2	.....	V E †	3444.36	3	.....	V E
3421.37	2	.....	V E	3444.45	1	.....	V E
3421.938	20	20	III	3444.577*	6	.....	V E
3422.353*	?	150	II	3444.705	3	.....	V E
3422.466(f)	10000	200	IV E	3446.313	30	200	II A
3422.751	500	4	IV E	3446.64	5	8	IV
3423.306	4	.....	V	3446.998	8	.....	V E †
3423.898(f)	1500	400	II	3447.444	2	.....	V E
3423.92			IV E	3448.325	20	.....	V E
3424.592	1200	6	IV E	3448.72	1	.....	V E †
3425.001*	8	15	IV A	3449.11	30	20	IV A
3425.624	50	.....	V E	3449.16		.....	V E
3425.930	600	3	IV E	3449.616	800	10	IV E
3426.25	10?	.....	V E	3450.16	8	.....	V
3426.342	50	.....	V E	3450.376	4000	25	IV E
3426.61	1d	.....	V E	3451.009	5	60	III A
3426.832	8	.....	V E	3451.233	2000	10	IV E
3426.882	5	.....	V E ?	3451.564	15	.....	V E
3427.124	5	12	IV A	3451.914	25	15	V E, IV
3427.362	80	.....	V E	3452.42	8	10	IV
3428.467	500	.....	V E	3453.78	4	.....	V
3429.37	8	.....	V E	3453.858	5	.....	V
3429.746	4	30	III A	3454.145	1500	12	IV
3430.137	8	.....	V E	3454.39	4	.....	V E
3430.238	40	.....	V E	3454.904	2000	20	IV E
3430.311	10	200	II A	3455.271	100	500	II A
3430.980	200	.....	V E	3455.819	5	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3456.735	1	.....	V E †	3489.281	40	.....	V E
3457.014(f)	300	125	III	3489.76	30	2	IV, V E
3457.047		?	V E	3490.124	2	.....	V
3457.416	5	.....	V E	3490.477	10	30	IV A
3457.54	1	5	IV A	3491.51	10	.....	V E
3457.938	8d?	150	III A	3491.737	150	.....	V E
3458.024	20	.....	V	3491.954	2000	100	IV E
3458.813	15	.....	V	3492.36	8	.....	V E
3459.165	12	.....	V	3493.404	3	.....	V E †
3460.52(f)	1	20	IV A	3494.032	80	.....	V E
3460.776	30	.....	V E	3494.21(f)	?	15	IV
3461.901	300	80	III	3494.404	3000	100	IV E
3461.952		.....	V E	3494.95	2	2	IV
3462.23	1	15	IV A	3495.04	2	.....	V E †
3462.997	200	5	IV E	3495.940	20	.....	V E
3463.142	15d?	.....	V E	3496.370	10	150	III A
3463.984	5000	100	IV E	3497.090	50	500	II A
3464.132	100?	.....	V E	3497.380	100	.....	V E
3464.924*	10?	8	IV	3498.154	30	300	II A
3465.05	2	.....	V E †	3499.155	2	100	III A
3466.498	150	.....	V E	3500.182	30	.....	V E
3466.952	600	2	IV E	3500.46	5	2	IV
3467.267	3500	80	IV E	3501.46	15	.....	V E
3467.664	40	.....	V E	3501.577	30	.....	V E
3468.083	200	.....	V E	3501.661	5	15	IV A
3468.131(f)	?	150	III A	3502.71	6	.....	V E
3468.989	3000	80	IV E	3503.206	60	.....	V E
3469.307	100	.....	V E	3504.72	2	2	IV
3470.237	3	.....	V E †	3504.91	30	100	III A, V E
3471.09	6	.....	V E	3505.024	6	20	IV A
3471.83	3	.....	V E	3505.512	2000	15	IV E
3472.122	15	.....	V	3506.7	2	.....	V E †
3472.23	2	.....	V E †	3507.457	20	200	III A
3472.37	1?	8	IV A	3507.556(f)	20	80	III A
3472.883	50	200	III A	3507.568		.....	V E
3472.997(f)	3?	100	IV A	3508.922	6	.....	V E
3473.219	2000	100	IV E	3509.387	1	50	IV A
3474.00	5	6	IV	3509.72	2	.....	V E
3475.37	3	5	IV	3510.133	30	.....	V E
3476.31	200	.....	V E	3510.449	10	200	III A
3478.027	20	.....	V E	3510.593	10	.....	V E
3478.072	15	.....	V E	3511.44	3	1	IV
3479.975	6	.....	V E	3512.219	800	8	IV E
3480.547	60	.....	V E	3512.496	600	4	IV E
3481.275	5000	100	IV E	3513.060	4d	3	V E, IV
3481.797	3000	60	IV E	3513.37	15	.....	V
3482.602	800	5	IV E	3513.654	300	1000	I A
3482.948	10	.....	V E	3514.51(f)	5	10	IV A
3483.759	25	.....	V E	3515.31	4	.....	V E
3483.942	12	.....	V E	3516.275	5	.....	V E
3484.99	10	.....	V	3516.776	60	.....	V E
3486.05	4	.....	V	3517.527	6	.....	V E ?
3486.195	100	500	V E, II A	3517.69	4	.....	V E ?
3486.44	5	.....	V E	3517.890	60	.....	V E
3487.5	2	.....	V E †	3518.632	30	.....	V E
3488.11	4	3	IV	3519.49	5d?	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3520.3	1		V E †	3564.046	60		V E
3521.3	2		V E †	3564.387	5		V E
3521.390	1		V E	3564.636	40		V E
3521.755	2		V E	3566.18	6		V E
3522.20	4d	6	IV	3567.116	30		V E
3522.446	50		V E	3567.211	30		V E
3524.196	1000	40	IV E	3567.654	40		V E
3524.580	4		V E	3567.72	2		V E
3524.659	4	50	III A	3568.2	1		V E
3525.147	60	300	II A	3569.566	40		V E
3525.32	4	4	IV	3570.412	30		V E
3526.33	3		V E	3571.933	300	10	IV E
3526.76	5	8	IV	3574.740	150	2	IV E
3527.266	1		V E †	3575.545	8		V E
3527.5	2	3	IV	3576.35	3	150	III A
3528.545	300	8	IV E	3576.444	10		V E
3529.932	4		V E	3576.772	25		V E
3530.197	25	40	II	3578.293	5		V E
3531.600	8		V E	3578.358	15		V E
3533.440	3		V	3578.410	6		V E
3533.71	2		V E	3578.596	30		V E
3534.030	25	200	II A	3578.88	8	30	III A
3534.238	40		V E	3579.549	25		V E
3534.87	3		V E	3580.618	40		V E
3534.976	20		V E	3580.90	10	150	II A
3535.32	4d?		V E	3581.91	200	?	V E
3536.33	8		V	3582.01	25	200	II A
3537.076	20	60	II A	3583.65	20d?	150	II A
3537.148	30		V E	3584.962	3000	50	IV E
3537.27	8d?		V	3585.523	12	100	II A
3537.510	25	250	II A	3586.576	10		V E
3540.361	5		V E	3587.186	40		V E
3540.456	15		V E	3588.207	15	150	II A
3541.492	6		V E	3589.75	3		V E
3542.341	15		V E	3590.468	100		V E
3542.768	500	2	IV E	3590.59	10	100	II A
3543.419	10?		V E	3591.00	1	5	IV A
3544.09	2	4	IV A	3591.442	20		V E
3544.985	60	10?	IV E ?	3591.912	30		V E
3545.68*	30?	5?	IV ?	3592.709*	1500d		V E
3545.797	3000	150	IV E	3593.445	60		V E
3548.308	30		V E	3594.44	6		V E ?
3548.537	12		V E	3594.709	6		V E
3548.98	12	100?	II A	3594.867	1		V
3549.365	3000	200	IV E	3595.64	1		V E
3550.630	8		V E	3596.36	8	20	III A
3553.716	40		V E	3596.644	1		V E
3554.26	4	30?	III A	3596.841	30	300	II A
3554.48	15d?	50?	III A ?	3596.903	1d?		V E
3554.802	30		V E	3597.014	1		V
3555.331	15	20?	III	3597.723	5		V E
3557.053	1000	5	IV E	3597.793	2		V E
3558.189	400		V E	3598.825	8		V E
3558.468	250	2	IV E	3599.16	4		V E
3561.24	5		V	3599.410	1		V E
3561.908	8		V E	3599.572	1		V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3600.042	1	.....	V	3625.26	60	.....	V E
3600.963	200	.....	V E	3625.50	4	40	IV A
3602.00	20	.....	V E	3626.32	40	.....	V E
3602.47	3	3	IV	3626.41	30	.....	V E
3602.959	1	.....	V E	3626.90	15	.....	V E
3603.76	1	.....	V	3627.72	4	.....	V E ?
3604.195	2	.....	V E	3628.1	1−	2	IV A
3604.31	2	25	IV A	3629.0	2	5	IV A
3604.704	3	.....	V E	3629.15	12d?	.....	V E
3604.87	500	800	I	3629.51	80	.....	V E
3605.265	100	.....	V E	3630.25	20	.....	V E
3605.665	100	5	IV E	3630.49	1−	.....	V E †
3605.80	2	8	IV A	3630.88	30	.....	V E
3606.347	2	.....	V	3631.09	8	30	IV A
3606.664	4	.....	V	3632.48	4	40	IV A
3606.776	2	.....	V	3634.757	100	.....	V E
3606.98	5	20	IV A	3635.25	2	.....	V E
3607.122	40	.....	V E	3635.82	2	.....	V E
3607.3	2	2	IV	3636.47	10d?	.....	V
3607.90	20	.....	V E	3636.66	1	15	IV A
3608.181	1	.....	V	3636.80	10	.....	V E
3608.753	200	.....	V E	3637.05	4	10	IV A
3609.02	5	.....	V E	3637.14	5	.....	V E
3609.19	10	.....	V E	3637.74	5	15	IV A
3609.41	2	.....	V E	3638.53	3	30	IV A
3609.484	2	.....	V E	3638.78	6	.....	V E
3610.107	4	.....	V E	3638.88	10	4	V E, IV
3610.3	2	2	IV	3639.05	30	.....	V E
3610.76	200	.....	V E	3639.10	5?	.....	V E
3610.91	100	.....	V E	3640.18	50	2	V E, IV
3611.40	3	50	IV A	3640.29	5	.....	V E
3611.85	2	5	IV A	3641.39	125	.....	V E
3612.880	15	.....	V E	3641.68	10	100	IV A
3613.392	150	.....	V E	3642.57	25	300	III A
3613.490	80	.....	V E	3642.80	1	.....	V E
3614.21	100	400	V E, II A	3643.57	1	.....	V E
3614.42	150	250	III	3644.59	4	.....	V E
3614.86	1	.....	V E ?	3645.35	6	.....	V E
3615.25	1	.....	V E	3645.62	300	6	IV E
3616.12	1	25	IV A	3646.19	3000	150	III E
3616.458	12	.....	V E	3646.480	30	300	II A
3617.164	200	4	IV E	3647.20	5	5	V E, IV
3617.47	1	20	IV A	3647.64	2	.....	V E
3618.06	15	.....	V E	3647.87	10	.....	V E
3618.376	2	.....	V E	3648.48	150d	500	II A
3618.783	6	.....	V E	3649.00	10	.....	V E
3620.456	150	.....	V E	3649.23	8	.....	V E
3620.71	4	.....	V E	3649.44	80	.....	V E
3621.28	6	.....	V E	3650.95	100	.....	V E
3621.88	2	5	IV A	3651.19	60	.....	V E
3622.0	2	.....	V E	3652.54	200	.....	V E
3622.2	1	.....	V E †	3653.11	1	.....	V E
3622.812	60	.....	V E	3653.39	1	.....	V E
3623.87	6	.....	V E	3654.62	2000d	100	III E
3624.893	80	.....	V E	3655.10	1	3	IV A
3624.95	?	80	IV A	3655.22	2	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3656.152	1500	60	IV E	3696.76	100	.....	V E
3656.74	4	5	IV	3696.93	50	200	II A
3657.15	5	.....	V E	3697.27	2	.....	V
3658.188	50	250	III A	3697.35	25	150	III A
3659.09	8	.....	V E	3697.73	1000	40	IV E
3660.2	1	.....	V E	3699.22	1	.....	V E
3661.52	3	.....	V E	3699.73	800	.....	V E
3661.663	30	.....	V E	3700.93	50	200	II A
3661.80	3	.....	V E	3702.48	2	.....	V E
3662.26	800	40	IV E	3702.81	6	.....	V E
3662.56	8	.....	V E	3703.51	15	.....	V E
3664.13	4	.....	V E	3704.14	2	.....	V E
3664.60	2000	8	IV E	3706.46	3	.....	V
3665.18	4	3	IV	3707.46	1	.....	V E
3665.90	6	.....	V E	3707.59	10	.....	V E
3666.30	2	.....	V E	3707.71	8	.....	V E
3667.25	3	30	IV A	3708.79	4	40	IV A
3668.32	25	.....	V E	3709.13	50	.....	V E
3669.18	2	.....	V E	3709.94	8	15	IV A
3669.4	1	.....	V E	3710.51	3	30	IV A
3669.5	1	.....	V E	3712.70	2000	25	IV E
3670.81	4	.....	V	3713.57	1200	1000	I
3671.20	1500	80	IV E	3713.76	5	.....	V E
3671.36	30	.....	V E	3715.23	8	.....	V E
3672.00	15	.....	V E	3715.92	50	300	II A
3672.27	3	2	IV	3716.36	1000	25	IV E
3673.16	10	.....	V	3716.97	4	.....	V E
3673.77	8	.....	V E	3717.48	1500	800	I
3674.05	400	400	I	3718.67	4	.....	V E
3674.22	10	25	IV A	3719.45	800	.....	V E
3674.43	12	.....	V E	3719.53	300	2	IV E
3674.78	3	.....	V	3719.81	4	15	II A
3675.68	8	.....	V	3720.08	2	.....	V E
3676.09	1	.....	V E	3721.74	4	.....	V
3676.91	2	.....	V	3722.068	100	.....	V E
3678.96	3	15	IV A	3723.24	8	.....	V E
3679.21	100	300	II A	3723.40	3	.....	V E
3679.54	20	150	III A	3723.69	20	.....	V E
3680.26	3	.....	V E	3725.47	200	300	V E, II
3682.73	20	.....	V E	3726.3	4	.....	V E
3684.13	1000	1000	I	3726.57	40	200	II A †
3685.01	30	200	II A	3726.70	8	80	III A
3685.80	5	.....	V E	3727.40	5	.....	V ? †
3685.91	5	40	III A	3728.2	1	.....	V E
3686.33	100	.....	V E	3729.38	4	.....	V E
3686.442	30	200	II A	3730.84	1000	15	IV E
3687.28	20	100	III A	3731.09	5	.....	V E
3687.74	800	15	IV E	3732.324	150	300	II A
3689.81	5	.....	V E	3732.45	100	.....	V E
3691.1	1	.....	V E †	3732.67	100	250	II A
3693.60	20	6	V E, IV	3733.08	300	.....	V E
3694.03	80	.....	V E	3736.44	40	100	IV A
3694.309	15	.....	V E	3737.26	10	.....	V E
3694.4	1—	.....	V E	3739.76	500	600	I
3694.73	6d?	.....	V E	3740.02	150	.....	V E
3695.96	3	.....	V E	3740.17	4	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3741.36	30	50	IV	3783.05	1200	600	I
3741.63	20	40	IV A	3783.73	20	.....	V E
3741.77	4	.....	V E	3787.15	10	125	III A
3741.91	30	.....	V E	3787.56	400	6	IV E
3743.47	2000	80	IV E	3789.66	12	15	III
3744.14	15d	.....	V	3790.44	20	.....	V E
3744.83	400	400	I	3790.63	150	200	II
3746.44	8	.....	V E	3791.17	300	.....	V E
3748.88	50	.....	V E	3791.72	30	.....	V E
3751.10	40	150	II A	3792.39	200	.....	V E
3752.23	3	.....	V	3793.15	4	.....	V
3752.66	8	.....	V E	3795.25	20	.....	V E
3753.56	10	.....	V E	3795.51	15	.....	V E
3753.9	1	.....	V E	3795.75	50	250	II A
3755.24	30	.....	V E	3795.93	40	.....	V E
3755.56	40	.....	V E	3796.37	2500	200	IV E
3756.03	4	.....	V	3798.39	20	.....	V E
3756.09	10	.....	V E	3798.66	6	10	IV
3757.65	4	.....	V E	3800.68	15	.....	V E
3757.74	80	.....	V E	3800.95	8	12	IV
3757.94	600	500	I	3801.29	400	.....	V E
3758.31	200	4	IV E	3801.7	3	.....	V E
3759.00	300	6	IV E	3802.85	40d?	.....	V E
3759.98	30	200	II A	3803.80	6	.....	V E
3760.47	60	60	III	3804.21	2	.....	V
3760.71	200	1	IV E	3804.39	80	80	III
3760.92	100	.....	V E	3805.09	80	.....	V E
3762.20	400	400	I	3805.31	20	.....	V
3763.00	50	.....	V E	3805.52	200	.....	V E
3763.33	60	.....	V E	3806.19	4	.....	V E
3764.151	15	.....	V E	3807.65	25	.....	V E
3764.205	50	.....	V E	3808.44	8	.....	V E
3764.31	5	8	IV	3808.79	6	50	III A
3764.60	50	.....	V E	3809.06	3	.....	V E ?
3765.875	5?	.....	V E	3810.25	5	.....	V E
3767.04	500	4	IV E	3812.19	8	.....	V E
3768.39	2000	125	IV E	3813.97	2000	60	IV E
3768.50	60	.....	V E	3814.74	100	.....	V E
3769.45	100	1	IV E	3815.70	2	.....	V E
3770.27	4	8	IV A	3816.64	250	8	IV E
3770.69	300	.....	V E	3818.27	8	100	III A
3771.21	20	.....	V E	3818.75	150	.....	V E
3771.26	40	150	II A	3821.51	20	4	IV, V E
3771.38	20	100	III A	3822.17	80	.....	V E
3772.25	3	2	IV	3823.20	12	.....	V E
3773.45	100	80	III	3824.15	50	40	IV
3774.30	80	.....	V E	3825.02	50	.....	V E
3776.83	100	100	III	3825.4	1−	.....	V E †
3777.33	4	.....	V	3825.68	3	.....	V
3778.45	15	.....	V	3826.05	200	.....	V E
3779.13	3	.....	V E	3826.56	4	.....	V
3779.83	20	.....	V E	3827.33	80	.....	V E
3780.52	6	.....	V E	3828.000	30	.....	V E
3780.64	2	.....	V	3828.38	15	6	III
3781.31	4	.....	V E	3828.69	6d?	.....	V E
3782.34	300	.....	V E	3829.404	4	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3829.462	4		V E	3880.05	5		V E
3830.10	3		V	3881.84	50		V E
3830.98	30		V E	3881.94	30		V E
3831.20	3		V E	3884.0	2		V E †
3831.80	100		V E	3884.32	2		V E †
3831.96	1		V	3884.66	15		V E †
3832.16	4		V E	3887.157	40		V E
3832.97	100	50?	III	3887.734	50	100	III A
3834.99	150		V E	3888.931	150	20	IV
3836.3	1—		V E †	3889.2	1	2	IV A
3836.91	300	3	IV E	3890.130	6		V E
3838.75	2		V E	3890.424	60d?	30	IV
3838.900	30	50	III	3890.850	30		V E
3839.16	20		V	3891.68	4		V E
3839.64	300	1	IV E	3892.723	15	10	IV
3840.265	60	100	II	3893.36	2		V
3842.20	400	1	IV E	3893.79	1		V E †
3843.275	500	150	I	3894.33	2		V E
3843.62	8	5	IV	3894.696	2000	15	IV E
3843.80	25		V E	3895.230	200		V E
3844.579	500	2	IV E	3895.791	400		V E
3845.47	20		V E	3895.952	20	20	IV
3846.49	80	60	IV	3896.416	10		V E
3847.62	5		V E	3897.321	30?	30	IV
3847.84	10	?	V ?	3898.402	10		V E
3849.30	5	6?	IV ?	3902.398	1000	4	IV E
3850.69	800	20?	IV E	3902.709	400	200	II
3850.97	1200	30	III E	3903.90	1		V E †
3851.68	6	30	IV A	3904.290	300	150	II
3852.45	1000	10?	IV E	3904.984	5		V E
3852.69	3		V	3905.6	1		V E
3854.177	50		V E	3905.646	600	200	II
3855.115	4		V	3906.060	3		V E
3855.56	200		V E	3906.18	1		V E
3858.45	60	30	III	3908.143	8		V E
3859.03	3	5?	IV ?	3909.25	10	10	IV
3860.22	4		V E	3909.940	15	20	III
3860.70	3		V	3910.20	6		V E
3860.97	4		V	3911.619	15	8	IV
3861.14	50		V E	3912.75	30	15	IV
3861.93	25	30	III	3913.70	1		V E
3862.10	2		V E	3913.785	20		V E
3863.05	150		V E	3916.508	3000	2	IV E
3863.98	8		V E	3916.67	60	25	IV
3864.79	40	30	III	3917.29	3		V E
3865.37	3		V	3918.061	150		V E
3866.989	500	150	I	3918.236	150		V E
3867.1	5?		V E	3918.77	4	1	IV
3867.26	60		V E	3918.90	2		V E
3871.54	80		V E	3919.99	6		V E
3872.62	60		V E	3921.25	2		V
3873.32	15		V E	3921.73	2		V E
3873.57	100	50	III	3921.85	3		V
3874.46	80	100	II	3922.63	1		V
3875.46	100		V E	3923.246	300	1	IV E
3879.1	1		V E	3923.329	80		V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3923.46	1		V E	3962.35	1		V
3923.569	4		V E	3962.53	1		V E
3924.200	6	1	IV	3963.38	1		V
3924.33	1		V E	3963.66	150		V E
3926.49	2		V	3963.89	1		V
3926.684	60	30	III	3964.20	1		V
3926.95	3		V E	3964.98	1	1	IV
3928.26	1		V E	3965.04	20	20	III
3931.28	1		V E	3966.275	600	400	II
3932.977	50		V E	3966.54	4		V
3933.43	2		V E	3966.64	2		V E
3934.790(f)	600?	500	I	3966.850	15		V E
3934.824	300?		V E	3967.17	2	1	IV, V E
3935.385	200	300	I	3968.261	60		V E
3937.77	1	5	IV A	3969.003	800	500	I
3937.85	3	1	IV	3969.293	300		V E
3938.114	40		V E	3970.185	20	25	IV
3938.971	50		V E	3971.062	100		V E
3940.25	3		V E	3971.754	300		V E
3940.58	2		V E	3972.166	30		V E
3941.19	1		V E	3972.706	500	400	I
3941.48	2		V E	3973.981	500	1	IV E
3941.800	300	300	II	3974.223	10		V E
3942.35	3	1	IV	3974.812	400	300	II
3942.633	400	400	I	3975.106	60		V E
3942.76	1		V E	3975.15	?	5	IV
3943.236	200	200	II	3976.57	1		V
3943.617	150	200	III	3976.87	3		V E
3944.088	6		V E	3977.94	1		V E
3945.541	800d	800	I	3979.333	1000	800	II
3945.75	8	40	III A	3979.751	6	3	IV
3946.972	30	20	IV	3979.88	1		V E
3947.12	2		V E	3980.122	4	4	IV
3947.874	5		V E	3980.25	1		V
3949.16	4		V	3982.35	2		V
3949.246	25		V E	3983.008	80		V E
3949.47	2		V E	3983.26	1		V
3950.06	1−		V E †	3983.52	1		V E
3950.46	1		V E †	3984.800	8	40	III A
3952.00	300		V E	3985.32	3	3	IV A
3952.395	2		V E	3985.671	8	4	IV
3952.60	1		V E	3987.214	600	3	IV E
3953.08	1		V E †	3987.835	600	600	II
3953.367	500	400	II	3988.4	1−		V E †
3955.698	6		V E	3989.248	50		V E
3956.137	8		V E	3989.448	3		V E
3957.672	1000	2	IV E	3990.11	2		V E
3958.680	50	150	III A	3991.692	15		V E
3958.98	1		V E †	3992.691	600	500	II
3959.25	3	3	IV	3992.92	4	2	IV
3959.436	300?		V E	3993.213	200		IV E
3959.523	500?		V E	3993.59	2		V
3960.108	150	100	III	3994.165	800	1	IV E
3960.99	1		V E	3995.45	5	4	IV
3961.15	2		V E	3996.320	800	1	IV E
3962.105	30		V E	3997.764	300		V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
3998.22	1		V E	4035.400	200	400	II A
4000.176	50	40	IV A	4036.21	5	2	IV
4000.51	5	2	IV	4036.68	2		V
4001.257	600	2	IV E	4036.839	150	200	III
4001.68	8	5	IV	4037.332	1500	3	IV E
4001.963	25		V E	4037.897	1200	2	IV E
4002.75	3		V E	4038.30	6	6	IV
4003.09	1—		V E	4038.89	1		V
4003.362	20	25	IV	4039.493	50		V E
4003.850	30		V E	4039.666	100		V E
4004.936	150		V E	4042.46	5d?	5	IV
4005.50	1		V E	4042.757	20		V E
4006.963	60	200	III A	4043.709	250	200	III
4007.88	2		V	4044.025	20	100	III A
4008.21	8	2	IV	4045.009	800	1200	I
4008.331	300	500	II A	4045.148	100		V E
4008.913	400		V E	4045.858	80	100	III
4009.223	80		V E	4046.38	4	4	IV
4011.36	8	3	IV	4046.845	150		V E
4011.42	2	10	IV A	4047.089	200	150	III
4012.42	2		V	4047.39	2		V
4013.14	1		V	4047.813	100		V E
4013.426	60	50	III	4048.08	3		V E
4013.798	250		V E	4048.597	80		V E
4013.953	60		V E	4048.864	20	30	III
4015.220	50	50	III	4049.199	200	150	III
4015.583	50	100	III A	4049.429	1200	1	IV E
4015.695	5		V	4049.54	20	40	III A
4016.918	2		V E †	4049.858	2000	2	IV E
4017.247	200	80	III	4050.29	10	4	IV
4017.713	400	100	III	4050.370	60	125	III A
4019.732	200	300	II	4051.62	15	20	IV
4020.38	8	4	IV	4052.82	3		V E
4021.935	20	5	IV	4053.294	1000		V E
4022.333	300		V E	4053.642	2500	1500	I
4022.73	1		V	4054.724	400	1000	I A
4022.91	1		V	4055.30	6d	2	IV
4023.143	1000	1000	I	4056.01	30		V E
4023.346	1000	1000	I	4058.219	2500	2000	I
4023.738	8	10	IV	4059.370	80		V E
4024.64	1		V E	4059.875	500	400	III
4026.56	3		V E	4060.20	8		V
4026.80	3	4	IV	4060.93	5	10	III A
4027.14	2		V E	4061.163	30	150	III A
4027.611	200	300	III	4061.296	80		V E
4027.89	2		V E †	4061.824	40	50	III
4028.153	800	300	III	4062.01	3	2	IV
4028.48	3	8	IV A	4062.590	500		V E
4030.883	800	300	III	4062.90	3		V
4031.33	1		V E †	4063.28	10?	3	IV
4032.161	5	6	IV	4063.390	1500	1	IV E
4033.08	8		V E	4063.59	200	1	IV E
4033.490	600	300	III	4064.10	2		V E
4033.72	3		V E	4064.24	1		V E
4034.02	3	3	IV	4064.45	3		V
4034.352	8	8	III	4064.7	1		V E †

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4065.61	15	.....	V E	4109.52	10	30	III A
4066.036	100	150	III	4109.83	1	.....	V E
4066.563	5	.....	V E	4110.433	30	.....	V E
4068.349	400	300	III	4110.602	150	.....	V E
4068.44		2	IV	4111.25	3	6	III A
4068.740	150	150	III	4111.438	500	.....	V E
4069.04	5	.....	V	4111.745	100	.....	V E
4069.83	5	.....	V	4112.935	50	30	III
4070.288	600	1	IV E	4113.61	4	4	IV
4070.390	200	1	IV E	4113.77	15	.....	V E
4070.64	5	.....	V	4115.376	80	.....	V E
4073.195	400	1	IV E	4118.50	2	.....	V
4073.759	1500	5	IV E	4119.209	40	10	III
4074.32	2	.....	V E	4119.379	80	.....	V E
4075.470	15	.....	V E	4120.56	2	.....	V E †
4078.444	1200	4	IV E	4121.028	8	8	V E, III
4078.700	3000	2000	I	4122.13	1	.....	V E
4079.18	1	.....	V E	4122.41	1	.....	V
4080.31	2	.....	V	4122.89	2	.....	V E
4080.530	100	500	II A	4123.000	20	.....	V E
4080.780	15	6	IV	4123.396	30	3	IV
4081.80	1	.....	V	4123.593	10	?	III A
4083.702	800	600	III	4125.778	40	20	IV
4083.937	8	.....	V E	4126.17	2	2	IV
4084.33	3	1	IV	4127.27	10	8	IV
4084.684	30	.....	V E	4127.721	25	.....	V E
4085.564	2000	3	IV E	4128.391	10	.....	V E
4087.12	2	.....	V E	4129.14	6	6	IV
4087.325	5	20	III A	4130.372	3000	10	IV E
4087.690	200	.....	V E	4131.475	200	.....	V E
4087.83	6	25	III A	4132.275	2000	6	IV E
4088.6	1	.....	V E †	4132.58	1	.....	V E
4088.807	10	.....	V E	4132.97	2	.....	V E
4090.09	2	2	IV	4134.162	1000	600	I
4090.210	3	3	IV	4135.437	4	.....	V E
4090.412	800	800	I	4136.63	1	.....	V
4090.74	8	5	III	4137.104	500	.....	V E
4090.95	5	5	IV	4138.028	20	20	III A
4091.748	30	20	III A	4139.72	3	.....	V
4091.968	4	5	III	4140.450	100	.....	V E
4092.713*	1500	1500?	I	4140.58	10	10	III
4093.720	250	300	III A	4141.017	25	.....	V E
4094.478	300	5	IV E	4142.38	10	2	IV
4098.030	20	.....	V E	4144.247	30	40	III
4098.606	3000	6	IV E	4148.79	20	5?	IV
4098.900	400	2	IV E	4148.86	150	400	II A
4100.265	800	1000	I	4149.3	1	.....	V E †
4101.30	20?	.....	V E	4149.478	80	40	III
4101.77	5	.....	V E	4150.613	20	.....	V E
4102.60	1	.....	V E	4151.626	30	.....	V E
4103.63	2	.....	V	4152.025	10	.....	V E
4104.07	1	.....	V E	4153.510	125	.....	V E
4104.987	60	40	III	4154.415	6	2	IV, V E
4105.792	15	.....	V E	4154.862	250	.....	V E
4108.401	50	.....	V E	4155.40	3	.....	V E
4108.96	1	.....	V E †	4157.784*	250d	300	II

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4158.48	10	5	III	4221.88	1		V
4162.732	500		V E	4222.58	5	10	III A
4163.092	250	100	III, V E	4223.020	60		V E
4164.24	2d		V E	4224.270	40	40	III
4167.159	40		V E	4225.028	200	500	II A
4167.267	150	250	II	4225.148	100		V E
4169.52	5	5	IV	4225.259	20	8	III
4169.58	3		V E	4225.45	6	2	IV
4170.108	150	10	V E, IV	4225.850	3000	2000	I
4171.55	2	4	IV A	4227.140	200		V E
4171.708	100	50	III	4227.4	2		V E
4172.65	1		V E	4227.72	4	6	IV
4173.556	100		V E	4229.803	200		V E
4175.538	2000	1000	I	4230.18	1		V
4176.794	15		V E	4231.026	5		V E
4179.6	3		V	4232.466	40		V E
4180.58	6		V	4232.928	40	5	IV
4182.767	60	50	III A	4235.00	2		V
4183.66	6	15	IV A	4235.07	15		V E
4184.252	2000	8	IV E	4235.881	60		V E
4187.96	10		V E	4237.82	2		V
4188.099	60		V E	4238.43	1		V E
4188.82	20	5	IV	4238.782	500		V E
4189.136	10	4	IV	4240.08	1		V
4190.20	50	40	III	4240.31	1		V
4190.43	5		V	4240.681	25	30	III
4190.776	1500	1000	I	4241.276	80		V E
4191.067	800	4	IV E	4242.02	2		V E
4191.355	10		V E	4242.27	2		V E
4191.626	800	600	I	4243.07	1		V
4192.35	3	2	IV	4243.24	1		V
4193.152	60		V E	4243.839	150		V E
4195.41	60		V E	4245.341	125	100	III
4195.851	20		V E	4245.7	1—		V E †
4197.069	150		V E	4246.38	2		V E
4197.681*	800		V E	4246.568	150		V E
4200.295	8	4	IV	4246.87	1		V
4201.97	3		V	4249.80	1		V E
4202.523	80		V E	4250.10	1		V E
4204.857	300	3	IV E	4250.277	40	40	III A
4206.667	10	15	III	4251.733	2000	15	IV E
4208.08	25	25	III	4252.50	3		V
4208.365	8		V E	4253.366	800	3	IV E
4208.752	8		V E	4253.612	800		V E
4208.87	1		V E ?	4254.060	20	25	III
4211.59	4		V	4255.406	15		V E
4212.001	800	5	IV E	4255.566	20		V E
4214.58	20		V E	4260.116	800	800	II
4215.023	600	?	IV ? E	4261.22	3		V
4215.256	20	5?	IV ?	4261.42	1		V
4216.47	8	2	IV	4262.092	2500	150	III, V E
4216.6	3	8	IV A	4262.31*	?	5	IV
4217.195	500	3	IV E	4263.43	2		V
4218.46	4		V	4264.013	5		V E
4219.05	1—	2	IV A	4264.71	1		V E
4219.7	2		V	4266.223	12	8	III

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4266.595	800	600	II	4299.86	5	2	IV
4267.002	600	500	II	4300.62	1		V
4268.731	150		V E	4301.85	3	2	IV
4270.28	60	50	III	4302.91	2		V
4270.41	1		V	4303.468	25	2	V E, IV
4270.80	20	15	III, V	4304.087	25		V E
4271.48	6		V	4304.55	2		V E
4271.66	2		V	4304.62	3	8	IV A
4271.9	1		V	4304.895	400		V E
4273.15	1		V	4305.2	1	3	IV A
4273.291	50	40	III	4305.69	4		V
4274.1	2?		V E	4306.340	1500	1500	I
4274.167	300	500	II	4307.306	5	1	IV
4274.42	2		V E	4307.54	2		V E
4274.90	1		V	4307.866	40		V E
4275.033	4		V E	4308.233	40		V E
4276.05	2		V	4308.38	20	20	III
4277.64	2?		V	4309.02	1		V
4277.98	1		V	4309.290	200	200	III
4278.12	1		V	4309.94	4	3	IV
4278.216	25		V E	4310.981	200		V E
4280.12	1		V E	4312.01	4		V
4280.490	1500	8	IV E	4313.845	2000	2000	I
4281.60	10d?	4	IV	4314.28	10		V E
4282.00	3		V	4314.400	400	300	III
4282.34	1	2	IV A	4315.64	4		V E
4282.788	50		V E	4315.89	4		V E
4284.57	5		V E	4316.052	600	4	IV E
4284.944	30	40	III	4316.266	150		V E
4285.33	1		V	4316.63	4	5	IV
4285.485	8	15	III A	4317.42	1		V
4285.819	400	200	III	4320.519	150	250	III
4286.122	300	400	II	4321.110	200		V E
4287.11	4	6	IV	4321.198	150	800	II A
4288.19	2		V E †	4322.014	4	20	III A
4288.4	1		V E †	4322.195	125	3	IV E
4289.43	2		V	4323.03	2		V E
4289.884	80		V E	4323.623	10d?	8	IV
4290.061	80	60	III	4324.064	150	2	IV E
4290.39	4		V	4324.37	2		V E ?
4290.56	1		V	4324.566	20		V E
4291.29	1		V	4325.566	200		V E
4291.39	4		V E	4325.693	600	2000	I A
4291.68	1		V	4326.00	4		V E
4292.31	5		V E	4326.324	20		V E
4292.747	25		V E	4326.61	3		V E
4293.05	3		V	4327.125	1500	2000	I, V E
4294.76	10	5	IV	4327.42	3	2	IV
4296.076	1000	3	IV E	4328.937	25	60	III A
4296.30	400		V E	4329.24	2	5	IV A
4296.505	6	8	IV	4329.580	200	300	III
4296.95	60	50	III	4330.319	20		V E
4297.173	400		V E	4330.606	600	3	IV E
4298.23	1		V E	4330.86	3	2	IV
4298.432	30		V E	4330.948	20		V E
4299.293	200	200	III	4331.379	100	250	III A

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4332.72	1	.....	V	4368.572	8	3	IV
4332.93	2	3	IV	4369.152	40	100	III A
4333.244	20	20	III	4369.771	500	5	IV E
4334.87	3	.....	V E	4370.180	40	150	III A
4335.17	3	.....	V	4370.32	6	4	IV
4335.290	25	.....	V E	4371.20	1	?	IV ?
4336.24	4	.....	V E	4371.34	1	?	IV ?
4336.63	5	4	IV	4372.03	4	6	IV
4336.78	8	4	IV	4373.6	5	.....	V E
4337.23	2	.....	V	4373.833	800	1500	I
4337.510	80	100	III, V E	4374.243	30	.....	V E
4338.88	2	4	IV A	4374.986	8	8	IV
4340.26	15	5	IV	4376.073	20	150	III A
4340.60	20?	20?	IV	4378.02	2	3	IV
4340.8	1	1	IV	4378.09	2	1	IV
4341.282	600	3	IV E	4378.561	40	150	III A
4341.90	2	4	IV A	4379.52	3	1	IV
4342.179	1500	5	IV E	4380.3	3d?	4	IV
4344.300	100	.....	V E	4380.642	100	.....	V E
4344.487	40	.....	V E	4381.15	3	.....	V E
4345.24	1	.....	V E	4381.40	3	.....	V E
4346.458	1500	2000	I	4382.061	60	.....	V E
4346.624	600	1000	I	4383.119	150	.....	V E
4347.310	400	.....	V E	4386.20	10	8	IV
4347.84	2	6	IV A	4386.72	2	.....	V E
4350.50	3	.....	V	4387.17	10	10	IV
4350.90	1	.....	V E	4387.674	300	4	IV E
4351.01	1	.....	V E	4388.98	15	.....	V E
4352.669	15	8	V E, IV	4389.39	1	.....	V
4352.89	2	.....	V E	4389.69	6	.....	V E
4353.39	1	.....	V	4389.884	50	100	III A
4353.789	20	8	III	4390.000*	25	30?	?
4354.064	40	.....	V E	4390.42	2	2	IV
4355.06	4	.....	V	4390.953	300	4	IV E
4356.08	2	4	IV A	4391.445	15	.....	V E
4356.74	10	.....	V E	4391.66	8	5	IV
4357.74	4	40	III A	4392.063	150	200	III
4357.87	10	.....	V E	4392.76	3	2	IV
4358.21	1	.....	V	4393.12	1d	.....	V
4358.77	1	.....	V	4394.09	1d?	1	IV
4359.152	40	.....	V E	4394.719	25	.....	V E
4359.636	30	.....	V E	4397.38	4?	4	IV
4360.14	10	8	IV	4397.51	300	1	IV E
4360.917	250	1	IV E	4397.66	3	3	IV
4361.59	1	1	IV	4399.0	1	.....	V
4362.16	2	2	IV	4399.4	1	1	IV
4362.30	4	.....	V E	4400.18	25	.....	V E
4363.35	1	4	IV A	4400.757	40	50	III
4364.140	25	.....	V E	4401.857	800	1000	I
4364.84	1	3	IV A	4402.40	1	1	IV
4365.22	1	1	IV	4403.14	200	150	III
4365.68	3d?	.....	V	4403.224	20	15	IV
4366.521	4	15	IV A	4406.67	400	?	IV E
4367.31	15	2	IV, V E	4407.21	10	4	IV
4368.03	4	.....	V E	4408.248	400	?	IV E
4368.43	1	.....	V	4408.58	5	.....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4409.254	100	100	III	4441.95	1−		V
4410.32	1		V E	4442.49	2	1	IV
4410.6	1	1?	IV ?		3	2	IV
4411.157	400	500	I	4443.28	1		V
4412.05	1		V	4444.983	15	8	IV
4412.50	1	1	IV	4445.531	3	2	IV
4412.71	1		V	4446.487	250	1	IV E
4413.44	20	10	III	4447.340	8	3	IV
4414.16	500	300	III	4447.98	2	1	IV A
4414.732	400	600	I	4448.17	5	15	III A
4415.02	20	25	III	4449.022	15	5	IV
4415.42	40	12	IV	4449.413	20	6	IV
4415.65	8	15	III A	4449.953	15		V E
4415.97	8	2	IV	4450.30	2	2	IV
4417.27	1	1	IV	4450.58	1	1	IV
4417.8	1		V	4451.02	1		V
4418.3	1		V E	4451.41	1		V
4419.032	800	3	IV E	4451.74	2	1	IV
4420.02	2		V E	4452.726	25	30	III
4420.637	4	2	IV	4453.931	60		V E
4421.24	200		V E	4454.64	1		V E
4421.64	2		V	4454.71	5	4	IV
4422.406	600	600	I	4455.19	1		V
4422.55	20		V E	4456.69	6d	3	IV
4422.92	3		V	4458.16	1		V
4423.30	1		V E	4458.32	5	2	IV
4424.102	40		V E	4458.41	6	2	IV
4424.36	3		V E	4461.073	8	3	IV
4425.014	30	30	III	4461.361	20	30	III
4425.95	1		V E	4462.828	50	30	III
4426.151	80		V E	4463.247	80		V E
4426.52	1	1	IV	4463.39	1	5	IV A
4427.033	20		V E	4464.34	3	2	IV
4427.606	60		V E	4464.745	150	80	III
4428.28	1		V E	4465.810	15	40	III A
4428.34	1	3	IV A	4466.547	500	?	V E
4428.944	6	15	III A	4466.604		50	III
4429.50	2		V E †	4467.08	300	150	III
4430.344	5		V E	4467.227	80		V E
4430.630	600	600	I	4468.21	5		V E
4431.759	40	100	III A	4468.90	1−		V
4433.40	4d?	1	IV	4469.11	1		V E
4433.635	60		V E	4470.462	5	4	IV
4433.86	2	2	IV	4471.29	200	1	IV E
4434.21	1		V	4473.280	20	150	II A
4434.31	3	1	IV	4473.4	1	2	IV A
4436.103	50	400	III A	4474.13	250	125	III
4436.225	200	1	IV E	4475.09	2	5	IV A
4436.75	1		IV	4476.116	300	200	I
4437.453	8		V E	4476.3	3	2	IV
4437.886*	8	?	IV ?	4477.09	2	1	IV
4438.13	30		V E	4478.48	6	4	V E, IV
4438.266*	150	8	IV E	4478.795	250	2	IV E
4438.46	10	6	IV	4479.832	2	6	III A
4439.57	1−		V	4481.056	300	4	IV E
4441.23	2		V	4482.00	2		V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4482.40	3	2	IV	4515.01	3	.....	V E
4482.49	5	.....	V E	4515.56	1	.....	V E ?
4483.328	300	1	IV E	4516.68	2	3	IV
4483.98	2	2	IV	4516.982	40	15	III
4484.29	2	.....	V	4517.10	30	.....	V E
4484.469	20	.....	V E	4518.01	1	.....	V E
4484.695	100	60	III	4518.41	1	.....	V E
4485.479	25	125	II A	4518.767	5	15	III A
4486.352	100	.....	V E	4519.655	500	500	I
4486.900	200	300	II	4520.070	150	.....	V E
4488.06	1	.....	V	4520.79	5	8	IV
4488.401	80	.....	V E	4521.296	100	.....	V E
4488.543	12	40	III A	4521.94	150	.....	V E
4489.74	3	4	III	4522.43*	?	4	IV
4490.76	1	.....	V	4522.82*	250	50?	III, V E
4491.270	6	10	III	4523.875	20	.....	V E
4492.032	8d?	4	IV	4524.118	80	40	III
4492.43	2	1	IV	4524.388	15	.....	V E
4493.01	1	.....	V E	4524.61	2	.....	V
4494.31	1	.....	V E	4524.73	3	2	IV
4494.6	1	1	IV	4525.61	5	.....	V E
4494.853	25	.....	V E	4526.03	5	8	IV
4496.615	10	30	III A	4529.12	1	.....	V
4497.127	300	200	I	4530.00	1	4	IV A
4497.315	100	50	III	4530.646	4	.....	V E
4497.56	5	2	IV	4530.91	3d?	.....	V
4498.276	300	2	IV E	4531.138	10	30	III A
4499.910	5	15	III A	4531.821	30	40	III
4500.640	20	.....	V E	4532.13	1	.....	V
4500.829	20	.....	V E	4533.514	12	12	IV
4501.12	1	.....	V	4536.56	5	.....	V E
4501.47	3	3	IV	4536.967	60	30	III
4502.304	2	8	III A	4537.813	600	600	I
4503.200	20	10	III	4539.21	3	5	IV
4503.790	20	100	II A	4539.76	2	2	IV
4504.960	12	20	III A	4540.016	200	.....	V E
4505.43	1	.....	V	4540.76	1	4	IV A
4505.77	2	1	IV	4541.18	5	2	IV
4506.212	400	300	I	4541.28	4	1	IV
4506.333	200	2	IV E	4542.031	200	300	I
4506.931	60	.....	V E	4542.74	12	25	III A
4507.064	8d	25	III A	4543.605	4	8	IV A
4507.660	40	25	III	4544.23	20	40	III A
4508.02	5	2	IV	4544.36	2	.....	V E
4508.4	1	.....	V E	4545.14	1	4	IV A
4508.81	3	2	IV	4545.8	1	.....	V E
4508.986	40	25	III	4546.70	1	.....	V
4509.082	50	.....	V E	4547.00	1—	.....	V
4509.56	1	.....	V	4548.00	150	100	III
4510.380	30d?	.....	V E	4549.49	4	10	III A
4512.43	4	12	III A	4549.74	1—	1	IV
4512.83	2	.....	V	4549.92	1	.....	V
4513.805	6	15	III A	4550.05	3	.....	V E
4514.505	200	.....	V E	4550.18	1	5	III A
4514.67	5	.....	V E	4550.41	3	.....	V E
4514.74	?	4	IV A	4550.954	150	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4551.455	30	.....	V E	4588.06	2	6	IV A
4552.44	2	.....	V E	4588.763	10	.....	V E
4552.98	1	.....	V	4589.544	6	30	III A
4554.989	50	.....	V E	4590.01*	4d	2	IV
4555.88	1	1	IV	4591.21	2	2	IV
4556.36	1—	.....	V	4591.50	1	.....	V E
4557.73	1—	.....	V	4591.79	3	2	IV
4558.080	250	2	IV E	4593.51	1	2	IV A
4558.94	1	.....	V	4594.26	4	3	IV
4559.24	1—	1	IV	4594.82	2	.....	V E
4559.616	5	4	IV	4595.337	6	25	III A
4561.083	25	20	IV	4596.978	400	2	IV E
4561.50	1	1	IV	4597.91	500	15	IV, IV E
4561.98	1—	.....	V	4598.897	300	200	III
4562.49	1—	.....	V	4601.05	500	4	IV E
4563.03	4	.....	V E	4602.30*	1	.....	V E
4563.397	10	.....	V E	4602.929	200	200	II
4563.69	4	3	IV	4605.578	4	.....	V E
4564.13	1	3	IV A	4606.058	25	6	IV
4564.590	6	15	IV A	4606.52	1	.....	V
4566.62	1	4	IV A	4606.641	8	.....	V E
4566.86	2	.....	V E	4607.19	1	2	IV A
4567.2	1	.....	V	4607.92	1	3	IV A
4567.42	1	.....	V	4608.030	40	.....	V E
4568.04	2	10	IV A	4608.581	8	100	III A
4568.60	1	3	IV A	4609.60	1—	.....	V
4568.74	1—	.....	V	4609.75	2	1	IV
4569.07	1—	.....	V	4610.17	1	.....	V
4570.04	1	.....	V E	4610.94	1	.....	V E
4570.36	1	.....	V E	4611.045	10	5	IV
4570.837	4	10	IV A	4611.589	4	1	IV
4570.977	40	.....	V E	4611.90	1—	.....	V E
4571.54	2	.....	V E	4612.1	1—	.....	V E
4572.05	2	2	IV	4613.33	1	3	IV A
4572.20	20d?	50	III A	4613.97	1	.....	V E
4572.43	4	15	III A	4614.497	300	200	III
4573.809	100	150	II	4614.94	3	4	IV
4575.907	150	150	III	4615.44	3	.....	V E
4578.24	1	1	IV	4616.54	8?	3	IV
4579.593	200	100	III	4619.140	25	20	III
4580.02	2	2	IV	4619.63	{8	.....	V E
4581.086	200	.....	V E		{6	4	IV
4581.294	250	250	II	4620.45	15d?	.....	V E
4581.65	3	1	IV	4621.78	2	2	IV
4582.332	20?	20	III A	4622.187	4	10	III A
4582.38	300	.....	V E	4622.311	10	15	III
4582.53	400	.....	V E	4622.63	8	.....	V E
4583.07	300	200	III	4624.417	60	100	III
4583.330	20	.....	V E	4626.67	3?	1	IV
4584.265	25	30	III	4627.66	40	.....	V E
4584.56	1	1	IV	4628.07	10?	2	IV
4585.17	2	3	IV	4628.41	5?	2	IV
4586.077	12	6	IV	4630.512	15	15	III
4586.63	1	.....	V	4631.54	2	1	IV
4586.992	80	40	III	4631.97	3	3	IV
4587.93	1	.....	V E	4632.45	8d?	4	IV

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4632.87	3	2?	IV	4677.629	6	100	III A
4634.81	5	3?	IV ?	4677.82	1	1	IV
4635.26	8	−?	V ?	4678.25	15	5	IV
4635.91	10	8	IV	4679.176	100	30	IV
4636.638	250	200	III	4680.043	200	200	III
4637.24	15	30	III A	4680.48	6	3?	IV ?
4638.597	10	1	IV	4680.651	8	20	IV
4639.001	200	.....	V E	4681.853	6	.....	V E
4639.39	1	.....	V	4682.2	1	.....	V
4640.037	40	30	III	4682.606	2	.....	V
4640.543	5	60	III A	4683.073	80	80	III
4641.29	15	6	IV	4683.334	500	250	III
4642.00	10	2	IV	4686.41	10	5	IV
4643.10	2	.....	V E	4686.51	3	−?	V ?
4645.39	8d	4	V	4687.36	2	40	III A
4645.999	40	40	III	4687.92	1−	.....	V
4646.326	40	.....	V E	4688.125	100	250	I A
4647.645	60	150	II A	4688.388	4	−?	V ?
4648.593	20	10	III	4688.90	3	2	IV
4648.703	25	20	III	4689.73	1	.....	V
4649.1	2	3	IV	4690.08	1	.....	V
4649.74	4	6	IV	4691.164	50	50	III
4649.98	6	.....	V E	4692.843	6	4	IV
4651.91	5	2	IV	4694.330	800	600	II
4652.313	20	15	III	4695.126	10	15	IV
4653.541	200	150	III	4695.486	150	30	IV
4653.75	10	.....	V E	4695.75	6	2	IV
4654.765	5	50	III A	4695.977	15	20	IV
4654.986	100	.....	V E	4696.769	10	5	IV
4655.48	2	.....	V	4697.422	300	500	II
4657.46	3	2?	IV ?	4699.03	2	.....	V E
4657.84	3	8	IV A	4701.37	1	.....	V
4658.608	15	100	III A	4701.7	1	.....	V
4658.97	3	.....	V E	4702.311	8	.....	V E
4659.421	20	.....	V E	4703.128	100d?	80	III
4659.848	12	25	III A	4704.02	2	.....	V
4660.47	1	.....	V	4704.286	6	25	III A
4661.19	2	2	IV	4705.76	5d?	3	IV
4661.67	4	1	IV	4707.03	2	.....	V
4664.272	30	.....	V E	4707.33	3	.....	V E
4665.0	1	.....	V	4707.892	5	100	III A
4665.6	1	.....	V	4708.3	1−	.....	V
4666.448	40	5	V E, IV	4709.785	200	500	I A
4667.2	1−	.....	V E	4710.19	1	.....	V
4668.28	6d?	?	IV ?	4710.58	1	.....	V
4669.64	3	2	IV	4710.80	1	.....	V
4670.42	1	4	IV A	4711.160	6	.....	V
4670.87	50	20	IV	4711.42	2	.....	V
4671.22	6	4?	IV ?	4711.685	6	.....	V E
4671.44	3	2?	IV ?	4711.975	80	.....	V E
4671.68	2	2?	IV ?	4712.51	2	.....	V
4674.07	2	2	IV	4712.804	50	.....	V E
4674.54	8	.....	V E	4715.2	1−	.....	V
4675.27	5	.....	V E	4715.499	6	2	IV
4675.78	8	.....	V E	4715.7	1−	.....	V
4676.99	8	.....	V E	4715.974	4	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class
	Arc	Furnace	
4716.576	30		V E
4717.2	1		V
4717.35	6d		V E, V
4717.5	2		V E
4718.714	15	30	III A
4719.040	60		V E
4720.560	4	2	IV
4721.273	50		V E
4721.464	80	20	IV
4722.2	1		V
4723.2	1		V
4723.728	40		V E
4725.784	20		V E
4726.725	40		V E
4727.43	3		V
4728.468	300		V E
4728.643	100	250	II A
4730.120	30	40	III
4731.85	3	4?	IV?
4732.60	600		V E
4733.63	2		V
4734.427	100		V E
4734.78	8	?	IV?
4735.746	400	400	II
4735.9	1		V
4736.58	4		V E
4736.85	1		V
4737.41	3		V E
4738.113	80	20	IV
4738.55	1	4	IV A
4739.89	3	2	IV
4741.06	3 1	5	IV
4742.1	1		V
4743.65	1000	800	II
4744.52	2		V
4745.3	1		V
4745.820	150	150	III
4746.4	1		V
4747.00	2	5	IV
4747.405	6	3	IV
4747.89	1		V
4748.62	3		V E
4748.94	1		V
4749.15	40	5	IV
4749.315	40		V E
4750.04	3	2	IV
4752.39	4		V
4752.65	4		V E
4753.258	50		V E
4755.347	30		V E
4755.50	40		V E
4755.59	30		V E
4756.15	1		V E
4757.791	80		V E
4758.262	200	600	I A
4758.696	800	400	II
4760.09	2		V E
4760.740	150	400	II A
4761.39	1		V
4763.825	125	40	IV
4765.05	2	4	IV A
4765.534	15		V E
4766.07	2		V
4766.93	40	2	IV
4767.240	1000	600	II
4768.760	15	10	IV
4770.06	2		V
4771.8	1		V
4772.728	30		V E
4773.09	15d?	10	IV
4773.8	1		V
4774.68	1		V
4775.44	8	8	IV
4775.64	8	15	IV A
4775.855	20		V E
4776.15	3		V E
4777.20	3d		V
4779.95	6		V E?
4780.987	60	20	IV
4781.133	50	15	IV
4781.917	300	600	I A
4783.467	30	15	IV
4783.558	30	15	IV
4784.20	4		V
4784.622	600	800	III
4785.48	6		V
4786.08	3	2	IV
4786.753	200	100	IV
4786.908	150		V E
4788.68	2		V
4789.14	6	8	IV
4791.150	40		V E
4791.61	30	10	IV
4793.265	20		V E
4793.444	30	5	IV
4794.70	1		V
4795.69	1		V
4796.03	1		V
4796.94	3		V E
4797.508	6		V E
4798.09	3		V
4799.633	50	30	IV
4799.859	60	?	V E
4800.100	60		V E
4800.30	3		V
4800.8	2		V
4801.05	500		V E
4801.91	2		V
4802.575	80		V E
4803.536	80		V E
4803.8	1		V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4805.817	100		V E	4856.72	150	6	IV
4806.165	40		V E	4857.7	1		V
4807.451	500	500	III	4858.3	1		V
4807.836	10	2	IV	4858.89	2		V
4808.013	30	10	IV	4859.224	60	50	IV
4809.0	1−		V	4859.400	30		V E
4809.968	15	15	IV	4860.47	5		V
4810.352	20	1	IV	4861.32	15		V E
4812.55	10	1	IV	4861.783	100	50	IV
4812.85	2		V	4862.27	25		V
4813.76	8		V E	4862.592	250	100	IV
4814.44	25	10	IV	4863.12	25	15	IV
4815.022	20	8	IV	4863.42	3		V
4815.39	1		V	4863.86	1		V
4815.911	3		V E	4864.56	6d?		V
4816.182	10	40	IV A	4864.80	1		V
4816.36	1		V	4865.02	400		V E
4816.832	150	50	IV	4866.04	5		V E
4817.37	3d		V	4866.396	60	5	IV
4819.797	30	50	IV	4868.87	4		V E
4821.17	1		V E	4870.042	150	50	IV
4821.691	1000	1000	I	4870.73	1		V
4821.955	60		V E	4871.505	200	100	IV
4823.050	10	4	IV	4871.62	80	20?	IV
4823.7	1		V	4871.94	10		V E
4824.00	4		V	4872.4	1		V
4825.1	1		V	4873.339	150		V E
4828.20*	15	2	IV	4873.73	2		V
4828.55	3		V E	4874.55	2		V
4829.938	80	20	IV	4874.77	2		V
4832.00	4	1	IV	4875.13	1		V
4832.89	2	2	IV	4875.30	4		V
4833.13	2		V	4875.966	50		V E
4834.232	300		V E	4876.22	2		V E ?
4834.46	8	2	IV	4877.08	4		V
4835.257	300	600	I A	4877.563	40	50	IV
4839.24	6		V	4878.049	30		V E
4839.616	40		V E	4878.485	40	6	IV
4840.03	2		V E	4878.94	4	3	IV A
4840.72	4		V	4880.29	1		V
4842.89	1		V	4881.084	250	80	IV
4843.82	20	20	IV	4881.36*	200	60?	IV
4844.32	10		V E	4881.925	200		V E
4845.4	1		V	4882.56	1−		V
4846.47	10	15	IV	4883.19	250	80	IV
4846.58	1		V E	4883.46*	15	2	IV
4846.84	5	2	IV	4883.57	1		V
4848.101	250	80	IV	4884.68	1		V
4850.25	1		V	4885.4	1		V
4850.82	5		V E	4886.44	8		V E
4851.862	25		V E	4888.01	6		V
4852.644	15	20	IV	4888.542	40		V E
4852.89	3		V	4888.724	30	15	IV
4854.14	40	60	IV	4889.193	80	30	IV
4856.17	100	15	IV	4889.99	1		V
4856.48	5	8	IV	4890.61*	5		V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4891.49	10	.....	V	4944.70	20	.....	V E
4891.99(b?)	40	.....	V	4944.80	5	6	IV
4892.11	30	.....	V E	4945.411	8	.....	V E
4892.57	30	4	IV	4945.743	50	3	IV
4893.40(b?)	10	.....	V	4946.01	4	.....	V E
4894.30	600	10	IV E	4948.35	2	.....	V
4894.99(b?)	15	.....	V	4948.557	60	5	IV
4897.5(b?)	4?	.....	V	4950.110	150	100	IV
4899.37	20	4	IV	4951.585	50	30	IV
4901.5(b?)	4	.....	V	4952.469*	200	800	II A
4902.38	30	2	IV	4952.865	15	.....	V
4902.80	50	10	IV	4953.147	100	50	IV
4903.6	4	.....	V	4954.025	50	.....	V E
4905.15(b?)	3?	.....	V	4955.432	60	80	IV
4905.68	2?	.....	V	4955.89	2	.....	V
4906.39	25	6	IV	4956.59	5	.....	V E
4910.123	100	150	IV	4956.803	60	6	IV
4910.838	50	.....	V E	4957.292	50	5	IV
4912.4(b?)	5?	.....	V	4957.533	50	5	IV
4914.44	20	.....	V	4958.45	8	.....	V
4915.833	100	100	IV	4958.788	800	125	IV, V E
4916.598	80	40	IV	4959.51	2	.....	V
4916.78	25	.....	V E	4960.02	3	.....	V
4918.15	5?	.....	V	4961.470	100	25	IV
4918.64	6	.....	V	4961.83	1	.....	V
4919.21	15	.....	V E	4964.10	2	.....	V
4919.45	8	5	IV	4965.047	60	.....	V E
4920.32	30	12	IV	4967.482	40	4	IV
4921.3	8?	.....	V E	4967.74	6	.....	V
4923.463	30	25	IV	4968.575	50	.....	V E
4923.578	60	.....	V E	4969.165	400	150	IV
4924.65	30?	8	V	4971.76	1	.....	V
4925.70	25	25	IV	4972.11	1	.....	V
4927.35	8	.....	V	4972.61	80	150	IV A
4929.84*	100	20	IV	4973.756	15	4	IV
4930.30	50	.....	V	4973.896	30	.....	V E
4930.69	100	6	IV	4974.253	25	2	IV
4932.13	2?	2	IV	4975.126	40	.....	V
4932.255	30	4	IV	4975.89	5	.....	V
4932.664	15	.....	V	4978.002	25	15	IV
4933.15	20	2	IV	4978.47	2	.....	V E
4933.452	20	.....	V E	4980.20	15	.....	V
4934.12*	400?	200?	IV	4980.97	4	.....	V
4934.8	4	.....	V	4981.31	20	.....	V E
4935.77	8	.....	V	4981.97	20	.....	V
4936.008	150	8	IV	4984.905	60	.....	V E
4936.155	50	.....	V E	4985.30	100d?	.....	V E
4936.33	200	80	IV	4985.49	3	.....	V
4936.93	20	.....	V E	4986.19	20	.....	V
4938.29	8	.....	V	4986.375	60	80	IV
4938.607	800	200	IV	4986.895	60	4	IV
4939.12	3	2	IV	4987.3	2	.....	V
4939.526	80	10	IV	4988.79	6	.....	V
4939.90	8	.....	V	4990.0	3	1?	IV ?
4941.05	3	.....	V	4991.41	5	.....	V
4942.57	40	40	IV	4991.72	1	.....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
4992.18	10	—?	V ?	5044.46	3		V
4992.53	1		V E	5046.68	1—		V
4993.11	20		V	5047.10	1—		V
4995.307	40	2	IV	5047.58	20	40	IV A
4995.85	25		V	5047.78	8		V
4996.30	10		V	5048.58	2		V
4996.56	3		V	5048.785	50		V E
4997.19	8	30	IV A	5050.57	3		V
4997.52	4		V	5050.878	300		V E
4998.373	200		V E	5051.26	2		V
4999.068	400	150	IV	5051.58	2d		V
5000.28	8	3	IV	5052.416	60		V E
5002.94	2		V	5054.26	2		V
5003.33	1		V	5054.86	15		V
5004.19	15d	25	IV	5055.72	3		V
5004.65	1		V	5056.193	20	?	IV ?
5005.018	30	1?	IV ?	5056.699	25		V E
5005.453	300	30	IV	5057.228	20		V E
5005.58	8		V	5058.95	4	10	IV A
5005.93	6		V	5060.876	30	3	IV
5007.20	1		V	5061.063	100d?		V E
5007.834	12	5	IV	5061.52	1		V
5009.63	6	20	IV A	5062.13	4		V
5010.821	400		V E	5062.862	150		V E
5011.741	150	40	IV	5063.595	50		V E
5012.039	12		V	5066.110	50	3	IV
5013.35	3		V	5066.412	20		V
5014.71	2		V E	5066.598	20		V
5015.04	1500	1500	II	5067.055	100		V E
5016.39	1—		V	5068.69	2		V
5017.209	25	15	IV	5068.994	15		V E
5017.80*	8	12?	IV	5070.194	80	20	IV
5019.361	100		V E	5071.023	200		V E
5020.368	80	60	V E ?, IV	5071.84	2		V
5020.75	1		V E	5072.49	5		V E
5021.83	3		V	5072.988	50		V
5023.133	200		V E	5073.741	100	?	IV ?
5024.77	5		V	5075.28	1		V
5025.82	1		V E ?	5076.79	3		V
5029.74	3		V E	5077.623	20	5	IV
5029.98	3		V	5078.74	4		V
5030.48	1		V E	5079.24	1		V
5031.290	250		V E	5079.97	1		V
5031.562	80		V E	5080.69	1		V
5032.90	1		V E	5081.56	10		V E
5034.73	2		V	5082.805	80	5	IV
5036.28	2		V E	5083.37	1		V
5036.70	3		V E	5083.87	15	1?	IV ?
5037.54	2		V	5086.22	3		V
5038.61	1		V	5088.795	40	1?	IV ?
5039.093	250	100	IV	5089.80	3d		V
5040.09	1		V	5090.77	10	5	V E, IV
5041.34	2		V E	5092.251	600		V E
5041.76	1		V	5092.92	3		V
5042.29	1		V	5093.659	60	40	IV
5043.06	1—		V	5094.13	1		V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5095.06	1	.....	V	5138.33	1	.....	V
5095.89	20	5	IV	5140.28	5	—?	V?
5096.063	200	.....	V E	5140.839	400	.....	V E
5096.931	80	150	IV A	5141.497	200	150	III
5097.32	12d	3	IV	5142.685	200	150	III
5098.38	400	.....	V E	5143.54*	12	—?	V?
5099.273	60	30	IV	5146.27	3	.....	V
5099.5	1	.....	V	5148.81	2	.....	V
5100.104	15	.....	V E	5149.16	1	.....	V
5100.40	1	.....	V	5149.375	20	.....	V E
5100.67	1	.....	V	5149.841	50	.....	V E
5100.937	100	.....	V E	5153.24	8	100?	III A
5101.25	1	.....	V	5154.48	5	.....	V
5102.763	60	100	IV	5155.13	1	.....	V
5103.136	12	.....	V E	5155.845	1500	1000	II
5103.45	2000	2000	II	5156.29	{10	.....	V E
5104.00	20	8	IV		{5	.....	V E
5104.87	3	.....	V	5156.76	200	.....	V E
5105.22	12	.....	V	5158.478	150	200?	III
5106.10	1	.....	V	5160.105	40	.....	V E
5106.71	2	.....	V	5160.896	100	.....	V E
5107.406	60	.....	V E	5161.614	20	.....	V E
5108.01	1	.....	V	5162.47*	50d	.....	V E
5108.91	500	.....	V E	5163.698	150	200	III
5109.27	2	.....	V	5164.06	3	—?	V?
5109.54	5	.....	V	5164.542	150	.....	V E
5111.930	30	.....	V E	5166.323	15	3?	IV
5112.32	2	.....	V	5167.82	3d?	.....	V E
5113.837	15	.....	V E	5168.01	2	.....	V E?
5114.92	2	.....	V	5171.693	80	1000	III A
5115.72	1	.....	V	5173.455	30	.....	V E
5117.06	5	.....	V	5174.42	5	.....	V E
5117.32	5	.....	V	5175.839	50	.....	V E
5118.02	1—	.....	V	5176.285	800	5	IV E
5118.50	1—	.....	V	5177.69	8	5	IV
5120.50	8	—?	V?	5178.104	100	.....	V E
5121.93	3	.....	V E	5178.843	100	15	IV, V E
5122.86	3	.....	V	5179.919	125	.....	V E
5123.652	60	.....	V E	5182.01	3	50	III A
5125.56	400	.....	V E	5183.802	50	800	III A
5126.08	2	.....	V	5184.05	4	.....	V
5126.774	25	.....	V E	5186.915	200	.....	V E
5127.86	15	—?	V?	5187.237	250	.....	V E
5128.07	12	.....	V E	5187.881	150	300	III A
5128.98	4	—?	V?	5188.23	2	.....	V
5129.47	4	.....	V E	5191.081	250	5	IV E
5130.28	200	.....	V E	5196.30	15	2	IV
5130.44	2	.....	V	5197.768	1200	1500	II
5130.98	3	.....	V E	5198.15	8	25	IV A
5131.35	1	.....	V	5198.66	1	.....	V
5132.223	50	50?	IV	5199.211	60	.....	V E
5133.29	3	.....	V	5200.549	30	.....	V E
5135.587	100	20?	IV	5200.83	1	.....	V
5135.74	15	?	IV?	5202.31	4	15	IV A
5136.038	200	200	III	5203.54	2	.....	V E
5137.07	1	.....	V	5205.5	1	.....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5205.64	6	.....	V E	5263.63	2	.....	V
5205.97	6	.....	V E	5263.806	100	1500	II A
5207.46	10	15	IV	5265.99	2	.....	V
5208.75	2	.....	V	5267.322	40	.....	V E
5210.488	200	.....	V E	5267.76	40	2?	IV
5211.024	100	1200	II A	5268.01	80	60	IV
5211.64	2	.....	V	5268.785	400	2000	II A
5211.88	1	.....	V E	5270.96	25	.....	V
5212.20	3	10	IV A	5271.510	30	.....	V
5213.04	5	.....	V E	5271.786	80	80	III
5213.55	2	.....	V	5272.13	3	2	IV
5214.67	6	.....	V	5272.367	80	2	IV
5215.50	3	5	IV	5272.66	8	.....	V E
5215.68	2	50	IV A	5272.908	200	300	III
5217.48	400	2500	II A	5273.80	2d?	.....	V
5217.84	5	.....	V	5274.25	3	.....	V
5219.40	2000	2000	II	5274.806	20	.....	V E
5220.16	15	1	IV, V E	5275.674	5	100	III A
5220.297	300	.....	V E	5276.510	30	40	IV
5222.98	5	6	IV	5276.64	4	2?	IV
5223.28	5	.....	V E	5278.63	3	.....	V
5224.21	1	1	IV	5279.93	5	8	IV
5224.66	8	25	IV A	5280.64	25	2	IV
5224.91	1	1	IV	5282.16	20	.....	V E
5225.60	1—	.....	V	5282.484	300	150	IV
5226.83	3	.....	V	5283.076	3000	2000	II
5229.897	12	300	III A	5283.852	150	8	IV
5230.46	3	1	IV	5284.45	15	.....	V E
5231.09	5	.....	V	5285.38	2	.....	V
5232.19	10	.....	V E	5285.83	8	.....	V E
5232.805	15	15	IV	5287.12	3	.....	V
5233.42	4d	.....	V	5288.61	2	.....	V
5233.931	400	400	III	5289.52	6	.....	V E
5237.03	8d?	.....	V E	5294.16	3	.....	V E
5237.454	60	60	IV	5295.33	2	.....	V
5239.49	4	.....	V	5295.55	8	.....	V
5239.99	1	.....	V	5296.335	40	80	IV A
5240.13	1	.....	V E	5296.65	6	.....	V E
5243.33	15	10	IV	5296.88	8	.....	V E
5244.380	40	2	IV	5298.58	80	30	IV
5245.16	10	5	IV	5298.82	1	10	IV A
5245.79	1	2	IV A	5301.67	4000	2500	II
5246.87	250d?	30	IV	5302.76	3000	2000	II
5248.69	1	8	IV A	5303.43	30	.....	V E
5251.180	2000	2000	III	5303.615	60	15	IV
5252.14*	500	500	III, V E	5304.26	25	1	IV
5252.61	1	.....	V	5304.923	25	.....	V E
5253.20	3	.....	V	5306.022	20	.....	V E
5254.75	300	500	III	5306.698	200	300	III
5255.805	1500	1500	III	5307.30	4000	3000	II
5256.030	50	.....	V E	5307.75	2	.....	V
5257.15	1	.....	V E	5307.87	2	3	IV
5259.652	40	4	IV	5308.62	4	.....	V E
5260.397	40	30	IV	5309.17	6	.....	V E
5260.810	60	6	IV	5311.552	12	4	IV
5263.09	2	.....	V	5311.841	100	8	IV

TABLE 2—*Continued*

λ	Intensity		Class
	Arc	Furnace	
5312.73	2	2	IV
5313.13	3		V
5315.794	20		V E
5315.94	4		V E
5316.801	100		V E
5317.97	2		V
5318.27	10	12	IV
5318.83	8		V E
5320.75	4		V
5320.92	15		V
5321.25	300	200	III
5321.496	2000	600	II
5321.777	4000	1500	II
5322.366	80	40	IV
5322.693	150	80	IV
5323.39	6		V
5324.10	15		V E
5325.78	5		V
5326.87	10d		V
5327.321	1000	400	III
5328.305	800	300	III
5329.15	2		V E
5330.03	3	20	IV A
5331.057	10		V E
5331.923	300	60	IV
5332.49	3d		V
5333.30	2000	600	III
5333.64	2		V
5334.65	5		V
5335.41	5		V
5335.65	2		V
5336.13	4		V
5337.530	300	80	III
5338.07	2		V
5338.99	1		V
5339.77	12	2	IV
5340.08	5		V
5340.29	6		V
5340.65	15d?		V
5341.168	80	150	III A
5341.814	80	1000	II A
5343.00	3000	800	III
5343.21	10?		V
5343.65	2		V
5344.66	3		V
5345.126	500	600	III
5345.676	400	1500	II A
5347.63	1		V E
5348.67	2000	1200	II
5349.662	30	2	IV
5350.13	8	4	IV
5350.38	4000	2000	III
5352.24	2		V
5353.26	3000	800	III
5354.411	60	6	IV
5355.77	3		V
5355.99	15	30	IV A
5356.13	5		V
5357.27	2		V
5357.59*	25?	8	IV
5357.790	50		V E
5358.72	1		V E
5359.179	100	10	IV
5359.41	2		V
5361.664	250	100	III
5361.92	8	5	IV
5362.165	15		V E
5362.599	10		V E
5364.69	2d		V
5365.380	500	200	III
5365.611	20		V E
5366.357	40	40	IV
5366.814	10		V E
5367.696	100	50	IV
5368.284	10		V E
5368.792	80	50	III
5369.612	150	50	IV
5369.919	800	600	II
5370.39	4		V E
5370.630	150	800	II
5370.745	800		II
5371.31	15		V
5371.621	40		V E
5372.216	300		V E
5374.70	10		V E
5374.96	6	1?	IV?
5375.393	100		V E
5376.25	8d?	15	IV A
5377.24	12	4	IV
5378.91	5	2	V E, IV
5380.278	25		V E
5383.17	2d		V
5384.154	250	100	IV
5384.48	1		V
5385.04	15		V E
5385.386	200	10	IV
5385.55	1		V
5387.05	8	15	IV A
5388.94	4d?		V E
5389.498	1000	300	III
5391.40	2		V
5391.69	15	5	IV
5392.143	12		V
5393.659	100		V E
5394.321	125		V E
5396.29	8d?	2	IV
5397.91	1		V
5398.55	6d		V
5399.572	80		V E
5399.96	20	8	IV
5400.66	1		V
5401.02	5		V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5401.49	2	20	IV A	5460.66	15	.....	V E
5402.69	4d	.....	V	5461.51	5	.....	V
5404.10	2	.....	V	5462.08	3	.....	V
5404.95	15	.....	V E	5463.260	30	30	IV
	5	.....	V E	5466.38	4	.....	V
5405.52	?	2	IV A	5466.59	3	.....	V
5407.31	4	.....	V	5469.05	100	.....	V E
5408.3	2	.....	V	5469.72	800	25	V E, IV
5411.197	150	40	IV	5470.53	50	.....	V E
5411.74	6	2	IV	5471.12	5	.....	V E
5412.642	200	.....	V E	5473.21	2	.....	V E
5413.20	800?	600?	III	5474.77	6	.....	V
5413.39	200?	200?	III	5475.14	4	.....	V
5415.69	800	500	III	5475.72	60	200	IV A
5416.26	4	.....	V	5476.29*	50	.....	V
5417.12	20	.....	V E	5477.20	5	6	IV
5418.30	4d?	.....	V	5479.80	1	.....	V
5419.876	150	.....	V E	5480.23	40	20	IV
5420.35	6	.....	V E	5482.01	50	30	IV
5421.188	200	800	II A	5484.21	10	2	IV
5423.63	40	.....	V E	5484.84	5	.....	V E
5424.08	4	.....	V	5485.36	3	8	IV A
5424.67	50	25	IV	5486.58	15	?	V ?
5425.61	12	10	IV	5487.53	2	1?	IV ?
5425.84	3	2	IV	5488.19	10	.....	V
5426.94	10	.....	V	5490.60	8	.....	V
5428.42	6	.....	V	5491.41	50	10	IV
5429.00	2	.....	V	5491.68	40	.....	V
5430.13	3	.....	V E	5492.19	1	6	IV A
5432.00	5	2	IV	5493.42	100	150	III
5432.891	15	2	IV	5494.89	1	.....	V
5436.304	300	200	III	5495.40	15	.....	V
5437.33	2	.....	V	5497.77	2	.....	V
5437.98	3	.....	V	5498.75	200	200	III
5438.51	4	.....	V	5499.97	500	150	IV
5439.54*	20	.....	V	5500.43	600	.....	V E
5441.17	40	.....	V E	5501.12	80	.....	V E
5441.582	100	100	III	5502.56	50	30	IV
5443.06	1	.....	V	5503.39	30	250	III A
5444.34	3	.....	V	5503.75	30	30	IV
5444.94	10	.....	V	5505.11	100	.....	V
5445.84	2	.....	V	5506.65	50	8	IV
5447.742	200	.....	V E	5508.76	40	5	IV
5448.86	5d?	.....	V	5510.58	80	.....	V E
5449.22	5	.....	V	5511.04	20	.....	V
5449.89	6	.....	V	5513.69	60	.....	V E
5450.57	4	.....	V	5513.85	50	.....	V
5452.06	8	15	IV A	5514.61	100	.....	V E
5452.28	8	.....	V	5515.38	5	.....	V
5452.68	50	.....	V E	5515.61	100	.....	V
5453.46	1000	200	IV	5516.21	1	.....	V
5455.31	200	60	III	5516.52	10	.....	V
5456.26	2	.....	V	5518.23	12	.....	V
5457.47	2	.....	V	5518.98	2	.....	V
5458.23	2	.....	V	5519.53	2	.....	V
5459.58	8	.....	V	5520.13	4	.....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5521.75	200	250	III	5588.07	15	.....	V E
5523.64	3	3	IV	5588.95*	100d	8?	IV ?
5524.60	150	.....	V E	5589.59	20	30	IV
5525.61*	4	.....	V	5591.85*	1000d	200	IV
5526.28	15d?	.....	V	5593.29*	4	3?	IV ?
5526.73	8	.....	V E	5593.49	25	80	III A
5527.45	15	.....	V	5594.13	500	50	IV
5528.49	2	.....	V	5594.67	8	.....	V
5529.20	1	.....	V	5597.21	200	.....	V E
5531.38	2	.....	V	5598.73	2	.....	V
5531.84	20	10	IV	5599.01	2	.....	V
5533.37	50	100	IV	5601.94	4	.....	V E
5534.30	80	.....	V	5603.58	10	20?	IV ?
5534.56	100	150	III	5604.12	3	.....	V
5535.21	60	.....	V	5604.89	50	.....	V E
5538.32	300	.....	V E	5605.18	10d?	.....	V
5539.81	200	.....	V E	5605.93	30	20?	IV ?
5541.52	4	.....	V	5607.27	4	.....	V
5544.15	4	.....	V	5608.23	8	10?	IV ?
5545.01	250	.....	V E	5609.03	3	.....	V E
5545.84	2	.....	V	5610.70	4	.....	V
5548.20*	400d	150	IV	5610.94	30	.....	V
5549.41	6	.....	V	5612.47	6	.....	V E
5550.21	100	200	III A	5613.02	2	.....	V
5550.91	1	.....	V	5613.67	2	.....	V
5552.05	1	.....	V	5614.45	125	1500	III A
5552.23	20	.....	V E	5616.21	300	.....	V E
5553.11	6	6?	IV ?	5616.87	8	.....	V
5554.42	15	.....	V E	5617.08	3	.....	V
5555.28	6	.....	V E	5617.91	4000	5000	I
5556.78	1	.....	V	5619.50	40	30	IV
5557.63	4	.....	V	5621.43	100	.....	V E
5558.73	3	5	IV	5622.92	60	.....	V E
5559.73	150	1500	III A	5624.76	10	.....	V E
5560.20	6	.....	V	5626.04*	2	2?	IV ?
5560.69	600	.....	V E	5628.79	10	100	III A
5561.27	5	.....	V	5629.55	800	2500	I A
5561.37	?	25	IV A	5630.31	15	.....	V E
5564.39	1	.....	V	5630.99	2	.....	V
5564.73	6	.....	V	5631.98	300	100	IV
5565.77	1	.....	V	5632.25	2500	3000	I
5568.80	10d?	.....	V	5633.49	200	300	III
5570.84	1	.....	V	5634.43	5	—?	V ?
5572.53	200	500	III A	5636.07	1	.....	V
5575.71	12	.....	V	5639.35	8	5	III
5576.13	200	500	III A	5640.22	2	.....	V
5579.66	60	.....	V	5643.24	6000	6000	I
5581.09	8	2	IV	5643.67	100	80	IV
5581.61	80	100	IV	5644.13	8	.....	V
5581.96	15	6	IV	5644.84	300	.....	V E
5583.68	800	.....	V E	5646.72	2	.....	V
5584.89	10	15	IV	5648.55	8	15	IV A
5586.16	100	.....	V, V E	5648.99	8	.....	V
5586.32	150	250	III	5650.90	10	20	IV A
5586.76	50	.....	V	5651.50	3d?	.....	V
5587.29	2	.....	V	5652.78	40	.....	V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5653.33	80	80	IV	5746.36	1000	3000	I A
5655.88(b?)	15	.....	V	5746.83	30	.....	V
5656.38	8	.....	V	5747.89	15d?	.....	V
5656.85	30	2	IV	5749.41	500	.....	V E
5657.64	8	.....	V	5751.88	300	2000	II A
5659.01	2	.....	V	5753.24	8	5	IV
5661.45	30	15	IV	5754.17	250	150	III, V E
5662.18	15	.....	V	5754.87	3	.....	V
5662.92	4	.....	V	5759.20	20	.....	V
5664.99	6?	3	IV	5759.94	6	.....	V
5667.40	8?	.....	V	5760.67	4	.....	V
5668.67	8?	.....	V	5762.38(b?)	6?	.....	V
5672.16	40	50	IV	5763.16	5	.....	V E
5674.53	8	150	III A	5769.76	100	200	III A
5675.55	20	30	IV	5770.05	20	.....	V E
5677.45	200	30	IV	5770.79(b?)	6	.....	V
5683.33	60?	.....	V	5771.20	20	.....	V E
5686.66	100	500	III A	5774.56	15	2	V E, IV
5688.67	5	.....	V	5774.94	4	.....	V
5689.48*	15d?	3?	IV	5776.02	200	150	III
5690.80	15	8	IV	5778.53	8	6	IV
5692.13	200	150	III	5779.00	2	.....	V
5692.49	5	10	IV A	5780.48(b?)	8	.....	V
5694.21	8	10	IV	5789.34	15	10	IV
5696.22	8000	8000	I	5790.02	?	.....	V E
5696.92	6	.....	V	5791.38	4000	5000	I
5697.99	60	30	IV	5792.22	5	1?	IV
5701.35	2500	3000	I	5793.85	2?	.....	V E
5703.42	5	.....	V	5796.80	100	15	IV
5703.78	10	.....	V	5799.65	20	1	IV
5705.94	10?	5	IV	5800.71	15	.....	V
5708.02	8?	5	IV	5801.30	40	.....	V E
5709.42	500	3000	II A	5802.92	400	3000	II A
5710.32	200	30	IV	5806.18(b?)	10?	.....	V
5711.35	15	2	IV	5807.05	100	.....	V E
5712.42	10	2	IV	5807.33	20	.....	V
5715.96	5?	.....	V	5807.59*	40?	?	IV ?
5716.55	8?	.....	V	5807.72*	40?	200	III A
5719.61	5?	.....	V	5808.21	20	.....	V
5720.01	10?	.....	V E	5809.22	300	30	IV
5720.64	?	.....	V E	5810.03	6	.....	V
5721.11	5?	.....	V	5811.81	10	.....	V
5721.99	200	.....	V E	5815.38	3	.....	V
5722.77	8	.....	V E	5815.85	250	.....	V E
5724.75	300	150	III	5819.51	50	.....	V
5727.68*	20	20?	IV	5820.10(b?)	15d?	.....	V
5728.32	60	.....	V E	5820.99	200	.....	V E
5732.16	100	1000	II A	5823.97	200	1500	II A
5733.86	4000	.....	V E	5827.75	5?	5	IV
5735.98	150	200	III	5830.17	8	4	IV
5737.39	5	.....	V	5832.24(b?)	10	.....	V
5737.59	20	.....	V E	5834.86	8?	1?	IV ?
5739.20(b?)	?	5	IV ?	5835.32	8	.....	V
5743.46	10?	10	IV	5836.11	6	.....	V
5744.66	400	2000	II A	5837.33	5	.....	V
5745.74(b?)	20	.....	V				

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
5839.78	15	3?	IV ?	5936.84	200	500	II A
5840.47	200	.....	V E	5937.71	150	400	II A
5840.94	6	8	IV	5940.95(b?)	40	.....	V
5843.36	12	.....	V	5942.22	40	.....	V
5845.71	80	.....	V E	5942.78(b?)	40	.....	V
5848.48	30	200	III A	5943.98	10	.....	V
5851.63	5000	8000	I	5951.60	80	.....	V E
5855.24	300	.....	V E	5955.92	3	.....	V
5856.22	4000	5000	I	5956.48	200	.....	V E
5856.96	150	.....	V E	5957.36	5	.....	V
5857.32	60	2?	IV ?	5957.72	2	.....	V
5858.02	40	3	IV	5958.34	5	.....	V
5860.73	1000	.....	V E	5959.54	2	.....	V
5861.62	5	.....	V	5962.75	4	.....	V
5865.61	5	.....	V	5963.17	30	150	III A
5867.65	4	.....	V E	5964.87	5?	.....	V E
5868.90	15	40	IV A	5967.83	10	.....	V
5870.17	10	.....	V	5969.15	6	.....	V
5870.58	50	25	IV	5970.32	60d?	.....	V E
5871.81	30	.....	V E	5976.20	30d?	.....	V E
5872.65	2	60	III A	5977.25	150	1200	II A
5876.73	15	100	III A	5977.69	15	.....	V E
5877.26	1000	.....	V E	5981.32	2	.....	V E
5879.89	10d?	5	IV	5981.87	6	.....	V
5882.21	60	.....	V E	5982.42	60	.....	V E
5884.59	30	.....	V E	5983.41	15	1000	II A
5884.8	5	.....	V E	5984.49	8	800	II A
5886.46	60	25	IV	5986.22	10	.....	V E
5889.58	?	30	IV A	5987.11	150	.....	V E
5891.44	5	.....	V	5988.02	50	25	IV
5897.62	200	.....	V E	5990.80	4	4	IV
5898.06	20	100	III A	5991.84	10?	6	IV
5899.31	2	6	IV A	5992.91*	?	3	IV
5900.37	5	.....	V	5995.13	.....	2	IV A
5900.95	5	.....	V	5995.74	5	2	IV
5901.67	10	.....	V E	5996.66	6	.....	IV
5904.07	800	.....	V E	5997.99	6	20	IV A
5904.56	800	5000	I A	5999.08	100	800	III A
5906.26	?	2	IV	6000.96	50	.....	V
5907.37	4	300	II A	6001.03*	?	.....	V E
5908.41	6	600	II A	6001.87	60	.....	V
5911.45	500	5	IV, V E	6003.10	10	.....	V
5912.07	4	.....	V	6004.57	500	.....	V E
5913.55	800	.....	V E	6006.36	15	.....	V
5914.06	5	.....	V	6007.13	5	.....	V
5916.77	50	800	II A	6007.44	10	.....	V
5917.31	6	.....	V	6008.71	20	30	IV
5919.79	4?	5	IV	6011.12	30	.....	V E
5921.35	40	.....	V E	6011.39	4	.....	V
5922.05	15	3	IV	6015.13	2	.....	V
5923.28	?	10	IV A	6015.82	6	.....	V
5929.68	6	.....	V	6019.01	20	200	II A
5930.29	200	1200	II A	6021.13	50	500	II A
5931.09(b?)	5	.....	V	6022.3	?	.....	V E
5931.99	2	.....	V	6024.08	5?	.....	V
5933.27(b?)	5	.....	V	6026.90	10	.....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
6028.18	10		V	6160.58	15		V
6030.75	6		V	6163.53	5	10	IV A
6036.05	5		V E	6164.47	40	80	III A
6037.93	10		V	6168.09	?	5	IV
6039.13	8		V	6170.55	10	−?	V ?
6040.15	8		V	6171.99	20?		V
6041.30	5		V E	6176.58	10?	40	III A
6044.01	20	50	III A	6178.55	15		V
6044.95(b?)	80		V	6180.42	300	15	IV, V E
6046.59	5		V	6182.69*	40?		V
6049.50*	80		V E	6186.97	6	10?	IV ?
6050.6	5?		V	6187.2	4	−?	V ?
6056.2	?		V E	6191.38	10		V
6059.88	30		V E	6192.43	20?		V
6061.29	8		V	6196.80	30?		V
6064.24	8	10	IV	6199.46	5	10	IV A
6065.14	4	2	IV	6200.06	25		V
6066.34	30		V	6203.61	20	25	IV
6071.34	5		V E	6207.32	6	2	IV
6072.01	5?	10	IV	6208.90(b?)	5		V
6074.35	8		V	6211.45*	?	3	IV
6080.65	300		V E	6212.15	4?	80	III A
6081.33	50		V E	6213.55	20		V E
6082.38	50	20	V E, IV	6217.87	5?		V E
6087.41	6		V	6220.27(b?)	15		V
6089.09	?	2	IV	6222.60	10		V
6093.9	?		V	6223.96	30?		V
6097.08	5	4	IV	6224.41	40?	2000	II A
6097.58	30		V	6225.90(b?)	10?		V E
6099.92	25		V	6228.44	20?	8	IV
6102.80	5		V	6229.87	5?	8	IV
6104.78	15		V E	6234.73	?	15	IV A
6105.92	5?	5	IV	6238.48	30		V E
6106.19	100		V E	6239.3	?		V E
6108.26	30		V	6244.33	20		V
6109.07	80	1500	I A	6247.92(b?)	10?	2?	IV ?
6110.31	5?		V	6254.99	5?	20	IV A
6113.48	2?	60	III A	6255.72	25	1000	II A
6114.07	2000	3000	I	6256.00	8?	−?	V ?
6116.9	2?		V	6258.45*	30?	2?	IV ?
6117.95	10		V	6259.87*	30?	10	IV
6122.88	6?		V E	6260.31	40		V E
6124.16	5		V E	6261.25(b?)	10?		V
6125.81	5?	30	III A	6263.62	10?	2	IV
6128.06	50	2	IV	6265.34	20	125	III A
6130.00	5?		V	6270.21	?	5?	IV ?
6135.02	15	600	II A	6275.73	4	4	IV
6135.95	25		V	6276.75	8	2	IV
6136.41	25?	800	II A	6280.48	10		V E
6138.34	40	40	IV	6280.88	15		V
6144.39	5	10	III A	6282.01	?	2	IV
6151.06	15?	150	III A	6289.68*	?	50	III A
6151.89	20		V	6289.73	200		V E
6153.12	?		V	6290.31	15		V
6154.11	15		V	6291.29*	?	80	III A
6158.92	8	2?	IV	6292.87	50	1500	I A

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
6294.19	30	.....	V	6422.42	200	.....	V E
6299.07	40	.....	V E	6423.87	3	1	IV
6299.25(f)	?	3	IV	6424.52	20	30	III
6302.27	10	8	IV	6432.74	2	10	IV A
6305.15	1500	.....	V E	6434.28	5	.....	V E
6308.95	5?	800	II A	6435.27	15	.....	V
6309.11	40	.....	V E	6438.07	2	50	III A
6309.63	?	6	IV	6439.38	3	2	IV
6310.55	5?	5	IV	6440.05	10	.....	V
6311.76	6	5	IV	6442.53	15	.....	V E
6312.88	4?	5	IV	6444.24	15	.....	V E
6314.22	50	.....	V E	6444.85	80	.....	V E
6315.93	10	.....	V	6449.08	4	.....	V E
6316.44	10	100	III A	6456.74	15	40	III A
6317.19	80	1500	II A	6459.69	10	30	III A
6321.59	5	2	IV	6463.29	10	2?	IV ?
6324.69	5	4?	IV	6463.59	10	.....	V
6328.18	3	.....	V	6466.57	50	.....	V E
6330.78	3	1	IV	6468.86	12	.....	V E
6331.35	150	25	IV	6469.80	2	4	IV A
6332.01	6	10	IV	6470.29	30	4	IV
6333.75	15	150	III A	6471.66	2	.....	V
6336.34	25	200	III A	6472.70	25d	4	IV
6345.98	4	4	IV	6473.68	20	.....	V E
6346.65	400	.....	V E	6480.11	200	.....	V E
6347.87	8	50	III A	6480.65	4	.....	V
6349.72	4	5	IV	6481.66	10	.....	V
6350.46	10	6	IV	6483.98	50	.....	V
6351.52	20	.....	V E	6494.11	80	.....	V E
6351.72	12	8	IV	6495.33	2	.....	V
6353.83	4	4?	IV	6497.95	2	.....	V
6355.61	6	.....	V E	6501.21	6	2?	IV ?
6358.26	1	1?	IV ?	6505.42	100	15	V E, IV
6358.37	3	.....	V E ?	6507.57	3	.....	V
6360.59	12	150	III	6508.54	15	.....	V E
6361.15	3	15	IV A	6509.27	4	.....	V
6363.23	20	10	IV	6511.62	2	.....	V
6368.81	50	.....	V E	6512.08	1?	8	IV A
6371.64*	3	10?	IV A	6514.23	100	.....	V E
6379.37	4	5	IV	6517.23	50	.....	V E
6380.95	600	.....	V E	6517.74	40	.....	V E
6382.19	150	.....	V E	6521.80	6	.....	V
6382.69	4	60	III A	6526.25	15	20	IV
6383.92	5	6	IV	6530.02	20	20	IV
6384.38	2	6	IV A	6530.98	60	.....	V E
6386.32	6	.....	V	6538.15	300	40	IV
6391.81	5	.....	V E	6544.86	5?	2?	IV ?
6392.21	10	10	IV	6547.28	10?	?	IV ?
6393.08	?	4	IV	6549.25	100	20	IV
6396.37	?	10	IV	6554.64	5	.....	V
6398.90	2	3	IV	6555.97	5	30	IV A
6402.38	3	20	IV A	6560.74	4?	20	IV A
6408.55	60	2000	II A	6563.70*	40	.....	V E ?
6414.26	2	5	IV A	6564.78	500	40	IV
6417.77	5	3	IV	6568.00*	100	.....	V E
6418.00	2	1?	IV ?	6571.76	4	.....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
6573.80	40	10	IV	6731.91	1		V
6578.49	5	400	II A	6735.85	2		V
6584.15	2		V	6738.84	3		V
6585.99	2		V	6744.52	3		V
6588.02	2		V	6752.67	2000		V E
6591.60	200	3000	II A	6753.91	200		V E
6593.42	100	10?	IV ?	6755.43	1		V
6594.25	2		V	6763.38	6		V
6600.63	{5 10}		V E	6764.61	3		V E
				6765.52	8		V E
6603.73	5		V	6766.92	15		V E
6604.54	6d	10	IV	6767.67	1		V E
6605.51	1?		V	6772.03	20	2?	IV ?
6607.98	3		V E	6776.97	8		V
6610.04	80		V E	6783.39	50	25	IV
6610.97	2	2	IV	6786.33	150		V E
6616.44	10		V E ?	6787.18	30	30	IV
6622.28	50		V E	6792.83	2		V
6628.43	40	10	IV	6795.85	10	10	IV
6630.13	2		V	6798.15	4d		V
6633.32*	3	20?	IV A	6800.68	3		V
6634.36	1500		V E	6802.68*	15?		V
6636.27	3		V	6810.89	6		V
6638.15	4		V	6813.17	6		V E
6639.73	3		V	6814.56	50	50	III
6640.08	300	4000	II A	6816.49	150	500	II A
6640.76	3		V	6820.90	60	5?	IV ?
6642.76	10	30	IV A	6821.90	8		V E
6643.98	150	30	IV	6822.75	10		V E
6644.18	80		V E	6823.20	10		V
6646.85	10	30	IV A	6827.03	6	2?	IV ?
6647.11	10	20	IV A	6828.25	1500	5000	I A
6648.96	12	5	IV	6834.82	10		V E
6651.07	8		V E	6835.05	3		V E
6653.55	10	10	IV	6839.24	3		V E
6656.62	15		V E	6844.63	2		V
6660.69	2		V E	6846.60	1200		V E
6667.00	4d?		V	6849.89	30		V
6668.74	1	—?	V	6852.94	4		V
6671.30	6		V E ?	6857.13	600		V E
6674.70	1		V	6858.43	5		V E
6679.31	2		V	6859.79	2		V
6679.56	80		V E	6861.75	4		V E
6681.23	1000		V E	6864.25	60	?	IV ?
6685.00	2		V E	6868.00	2		V
6689.46	1		V	6871.5	1		V
6692.86	20	60	IV A	6877.0	2		V
6694.92	8		V E	6878.51	15		V E
6695.76	1		V	6879.0	2		V
6702.12	40		V E	6880.95	4		V
6704.18	60		V E	6884.40	10		V E
6713.08	4		V E	6885.71	4		V E
6718.14	150		V E	6887.63	300		V E
6724.18	3		V E	6891.41	4	4?	IV ?
6727.83	125		V E	6892.14	10		V
6730.73	1500	5000	I A	6893.22	5		V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
6895.90	15	10	IV	6999.06	4		V
6898.11	2		V	7000.75	200		V E
6898.99	8		V	7003.24	4		V
6900.73	200		V E	7004.30	4	2?	IV ?
6904.40	2		V	7006.16	1000		V E
6905.50	40		V	7007.45	15		V E
6906.90	15		V E	7011.4	3d?		V E
6907.1	1		V	7012.50	12		V E
6913.41	5		V	7013.70	1	10	IV A
6916.57	2000	4000	I A	7016.60	80	60	III
6919.61	25		V E	7017.27	1		V
6920.62	250		V E	7017.73	60		V E
6924.28	3		V	7029.30	4		V
6924.99	125		V E	7031.41	4		V
6926.49	150	50	III	7036.0	2		V
6927.0	1		V	7037.26	600		V E
6927.31	2		V	7037.81	30		V E
6928.39	5		V	7043.30	20		V E
6931.40	1		V	7045.02	80		V E
6932.32	12		V	7045.40	2		V E
6933.16	5		V	7051.00	200		V E
6934.23	3		V	7052.79	80	300	II A
6936.5	1		V	7053.43	8		V
6938.48	20		V E	7054.62	200		V E
6939.63	10		V E	7055.7	2		V
6942.39	3		V	7056.69	6		V E
6943.06	12		V E	7058.02	80		V E
6944.40	1—		V	7062.86	6		V
6945.05	8		V E	7063.34	1		V E
6945.98	150		V E	7064.59	2		V E
6947.28	15		V E	7065.80	12		V E
6949.12	3		V	7068.09	150		V E
6949.67	6		V E	7069.24	1		V E
6950.35*	5		V	7069.93	80		V E
6951.74	8		V E	7071.00	250	50	IV
6952.53	2		V	7072.12	1		V
6953.43	5?		V	7072.78	2		V
6956.88	5		V	7073.63	250	1000	II A
6957.74	150		V E	7074.26	2		V
6959.24	150		V E	7074.60	2	5	IV A
6964.33	50	20	IV	7076.13	6		V
6969.81	5		V	7082.02	3		V
6971.66	100		V E	7082.70	4		V E
6976.35	125		V E	7084.18	20	—?	V E, V ?
6977.27	2		V	7085.52	50		V E
6978.27	60		V E	7087.57	2		V
6980.86	250		V E, V	7089.68	2		V
6982.57	2		V	7093.90	25		V
6983.53	20	2?	IV ?	7094.77	2		V E
6984.50	1		V	7098.11	125	20	IV
6985.89	1500		V E	7098.73	80	500	II A
6988.75	100		V E	7099.44	20	2?	IV ?
6991.92	1500	3000	I A	7100.71	40	10	IV
6993.18	200	40	IV	7101.73	20		V E
6996.76	1500		V E	7103.49	3	10	IV A
6997.8	1		V E	7105.22	2		V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
7108.08	1—		V	7246.39	3?	15	IV A
7109.83	10		V E	7246.80	1		V
7113.23	10	10	IV	7252.70	400		V E
7116.77	150		V E	7258.17	1		V
7118.86	800		V E	7262.66	125	1500	II A
7119.54	4		V	7279.40	4	4	IV
7120.61	4		V E ?	7282.59	2	10	IV A
7121.43	3		V E	7291.35	30	600	II A
7122.57	800	3000	I A	7292.38	2		V E
7123.63	2		V	7295.43	4		V E
7124.34	8		V E	7299.33	6?		V E
7125.38	2		V	7301.22*	50?		V E
7126.00	1		V	7303.74	2		V
7127.01	3		V	7304.12	2		V E
7128.2	1		V	7308.38	{3 2}		V E
7129.76	2		V				
7132.06	2		V	7313.28	50	1000	II A
7133.16	100		V E	7324.89	400		V E
7135.73	250		V E	7327.07	8	2?	IV ?
7136.15	4		V	7329.24	4?		V E
7141.17	25		V E	7342.40	1—		V E
7146.13	40		V E	7346.55	1		V E
7146.91	6		V	7347.33	1		V E
7147.31	500		V E	7348.62	1		V
7148.15	6		V	7360.95	2		V
7150.77	25	30	IV	7373.81	25	25	IV
7152.95	5		V	7376.41	30	40	IV
7153.12	15		V E	7377.27	200		V E
7158.28	150	50	III	7377.77	6	8	IV
7163.52	1	1	IV	7379.15	2		V
7164.30	80		V E	7380.28	20	25	IV
7164.90	25		V E	7381.22	4		V E
7168.37	3000	2000	I	7385.62	2		V
7169.85	4		V E	7385.97	80		V E
7170.48	2		V E	7386.62	20		V E
7170.87	1		V	7394.90	150		V E
7172.26	600		V E	7395.47	1		V E
7173.40	12		V E	7417.93	4		V
7185.59	1		V	7424.72	1		V
7189.57	800		V E	7430.19	15	150	II A
7191.49	20		V E	7432.57*	60d?		V E
7195.87	1		V	7434.46	6		V
7197.08	80		V E	7437.64	6		V E
7198.63	2	5?	IV A ?	7438.90	1		V
7201.41	150		V E	7439.04			V
7204.59	4		V E	7440.75	10		V E
7206.24	3?		V	7441.85	200	600	1 A
7210.91	1—		V	7464.36	200	600	1 A
7212.64	4		V E	7589.44	80		V E
7220.39	5		V E	7505.35	80		V E
7228.02	20	25	IV	7511.15	15?		V E
7230.20	4	—?	V ?	7517.94	10?		V E
7233.45	100	1500	II A	7526.57	15		V E
7237.92	1		V E	7535.29	6		V E
7240.29	2		V	7536.79	1		V E
7242.24	60		V E	7538.74	4		V E

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
7541.41	10	.....	V E	7847.65	4	4	IV
7556.42	20	.....	V E	7851.12	12	.....	V E
7562.97	150	400	I A	7854.90	10	.....	V E
7563.19	200	.....	V E	7856.93	1000	400	III
7566.10	8	5	IV	7859.15	1	.....	V
7567.30	2	.....	V E	7867.73	20	.....	V
7575.41	1	.....	V	7869.72	200	20	IV
7576.50	3	.....	V	7884.39	20	20	IV
7582.91	8	.....	V	7886.68	12	.....	V E
7583.86	3	.....	V	7902.31	20	.....	V
7588.20	15	5	IV	7908.06	40d?	.....	V E
7592.77	1?	.....	V E	7910.08	200	—?	V ?
7594.56	2	.....	V	7920.98	6	.....	V E
7597.37	8d	.....	V E	7925.28	4	.....	V
7603.08	3	.....	V	7930.25	2000	.....	V E
7605.38	5	.....	V	7934.33	20	2?	IV ?
7611.78	15	5	IV	7936.11	5	.....	V
7615.55	4	.....	V	7944.28	40?	.....	V
7618.76	5	.....	V	7945.01	15	.....	V
7621.19	5	.....	V	7963.25	500	.....	V E
7621.96	40	30	IV	7966.66	25	15	IV
7642.48	5	.....	V	7971.46	1	.....	V
7644.65	8	.....	V	7978.15	150	60	III
7650.32	80	60	IV	7987.67	8	?	V ?
7665.23	3	.....	V	7993.82	80	10	IV
7666.79	12	.....	V	7995.60	10?	?	V ?
7672.56	100	80	IV	7996.48	3	.....	V
7676.06	15	8	IV	8005.44	2	.....	V
7677.16	8	.....	V	8006.26	50	30	IV
7683.36	12d	.....	V	8010.53	200	.....	V E
7685.44	12	.....	V	8019.82	80	40	IV
7694.45	30	30	IV	8037.40	25	.....	V
7716.59	6	.....	V	8048.08	40	30	IV
7717.66	6	15	IV A	8048.96	6	.....	V
7733.50	1500	2000	I	8051.94	3	.....	V
7738.09	150	.....	V E	8056.36	2	.....	V
7748.37	40	.....	V E	8059.78	5	.....	V
7748.96	5?	?	IV ?	8060.22	5?	.....	V
7749.30	400	800	I A	8061.28	2	.....	V
7755.97	30	20	IV	8076.27	4	5?	IV ?
7761.00	6	10	IV	8077.59	150	100	IV
7762.26	1	.....	V	8079.74	1	.....	V
7766.48	15	5	IV	8089.96	60	.....	V E
7769.24	5	.....	V	8096.47	40	.....	V
7772.90	1	.....	V	8097.2	1	.....	V
7773.45	4	.....	V E	8117.31	20?	.....	V E
7779.01	12	.....	V	8119.36	20	.....	V
7787.22	150	.....	V E	8144.00	30?	.....	V
7795.96	3	.....	V	8146.15	1000	1000	III
7801.16	1	.....	V	8160.84	20	10?	IV ?
7802.20	1	.....	V	8164.26	4	2	III
7834.46	12	10	IV	8164.80	20?	?	IV ?
7838.84	200	.....	V E	8165.18	30	5	IV
7844.87	300	10	IV, V E	8177.37	3	.....	V
7845.80	20	.....	V E ?	8179.72	40	.....	V
7846.35	3000	.....	V E	8185.90	20	5?	IV ?

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
8187.70	15	.....	V E	8490.62	3	.....	V
8191.48	3	.....	V	8494.25	4	.....	V
8191.90	2	.....	V	8495.19	2	.....	V
8196.46	4	.....	V	8499.80	8?	?	V ?
8197.45	4	.....	V	8502.56	100d?	?	IV ?
8202.39	2	.....	V	8511.61	2	.....	V
8209.07	40	.....	V	8516.19	5?	?	V ?
8214.88	10?	?	V ?	8527.88	1000	600	III
8218.08	500	400	III	8528.90	4	.....	V
8235.3	2	.....	V	8539.33	6?	.....	V
8235.67	15	.....	V E	8552.2	10	.....	V E
8241.13	1	.....	V	8552.41	30	.....	V E
8244.48	3	.....	V	8559.11	50	.....	V
8249.68	2	.....	V	8561.72	300	200	III
8260.31	5	.....	V	8566.22	12d?	—?	V ?
8266.2	5?	?	V ?	8573.28	10?	?	V ?
8267.50	40	.....	V	8578.60	2?	.....	V
8272.90	6	.....	V	8579.77	100	.....	V E
8275.42	400	300	III	8594.06	15	2?	IV ?
8286.68	2	—?	V ?	8594.95	50	10	IV
8299.94	5	.....	V	8596.6	2	.....	V
8315.02	200	.....	V E	8597.35	8	.....	V E
8316.38	500	.....	V E	8598.76	50	.....	V E
8329.54	5	.....	V	8606.23	3	?	V ?
8331.30	200?	.....	V E	8615.97	40	.....	V E
8332.74	80d?	.....	V	8621.02	2	.....	V E
8335.03	4	.....	V E	8630.62	4	.....	V
8336.49	2	.....	V	8636.68	2	—?	V
8339.80	10	.....	V	8649.26	20?	?	V ?
8349.73	500	300	III	8650.53	8	.....	V
8358.17	5?	?	V ?	8658.53	10	.....	V
8370.16	25	?	V ?	8659.66	100	.....	V E
8373.73	4	.....	V	8661.48	400	40?	IV ?
8374.76	100	.....	V	8668.63	1500d?	1000	III
8375.98	30	.....	V	8674.86	80	.....	V
8377.79	150	?	V ?	8678.18	10	.....	V
8385.39	4	.....	V	8686.78	4?	.....	VE
8396.56	2	—?	V E	8695.36	8?	?	V ?
8398.30	800	500	III	8702.17	12d?	.....	V
8400.47	2	.....	V	8702.83	15	—?	V ?
8401.12	60	.....	V	8703.15	5	?	V ?
8402.87	8	.....	V	8717.6	2	.....	V
8418.60	20	.....	V	8718.69	8	.....	V
8429.43	8d?	?	V ?	8718.89	10	.....	V
8436.13	15	.....	V	8719.31	8	.....	V
8437.84	6	.....	V	8733.12	15	.....	V
8442.58	300	.....	V E	8733.89	8	.....	V
8445.47	500	400	III	8741.68	10?	.....	V
8447.33	20	.....	V	8748.56	5	.....	V
8457.2	1	.....	V	8750.30	6	.....	V E
8458.83	15?	.....	V	8751.70	15	?	V ?
8461.45	4	.....	V E	8752.77	30	.....	V
8477.95	5	.....	V	8756.40	6	.....	V
8485.04	10?	.....	V E	8757.80	6	—?	V ?
8486.89	40	5?	IV ?	8761.81	4	?	V ?
8490.20	1	.....	V	8764.95	2	.....	V

TABLE 2—*Continued*

λ	Intensity		Class	λ	Intensity		Class
	Arc	Furnace			Arc	Furnace	
8770.36	150	40?	IV?	8881.64	5	?	V?
8772.95	2	.....	V	8894.74	3	5?	IV?
8784.85	80	50	III	8900.87	1	.....	V
8791.26	8	.....	V	8905.26	6	.....	V E
8795.76	60	40	III	8907.57	2	.....	V
8801.60	4	.....	V	8915.45	10d	.....	V
8810.10	2	.....	V	8926.46	4	.....	V
8814.39	3	2?	IV?	8932.02	15	?	V?
8815.88	3	?	V?	8965.16	1	.....	V
8817.60	4	.....	V	8966.41	5	.....	V
8825.25	10	.....	V E	8974.99	8	.....	V E?
8830.32	6	.....	V	8981.68	3	.....	V
8831.32	8	.....	V E	8983.49	10	.....	V
8832.06	125	.....	V E	9000.75	10	.....	V
8839.93	2	.....	V	9004.80	2	.....	V E
8845.35	5	.....	V	9006.4	1	.....	V
8849.14	20	?	V?	9908.0	1	?	V?
8851.40	2	.....	V	9025.15	10	.....	V
8858.58	3	.....	V	9070.8	4	.....	V
8867.31	25	10	IV	9077.76	5	.....	V
8870.81	3	.....	V	9081.04	2	2?	IV?
8874.02	2	.....	V				

NOTES TO TABLE 2

λ		λ	
2770.983	Red component stronger	4262.31	Furnace λ; blend λ 4262.092 in arc
2877.02	Blend λ 2877.063	4390.000	Class uncertain; blend *V* in furnace
2881.329	Given as faint line by both Eder and M.I.T.; strong on present plates and well separated from *Si* λ 2881.58 when *Si* was present	4437.886	Blend *V* in furnace
		4438.266	May be blend with *Gd* I
		4522.43	Blend *Eu* in arc
		4522.82	Blend *Ti* in furnace
2892.084		4590.01	Violet component stronger
2903.752		4602.30	Faint component to violet
2904.600	Classes assigned on account of appearance in absorption at medium temperature	4828.20	Diffuse
2927.398		4881.36	Blend *V* in furnace
2945.574		4883.46	Faint line to red
2952.43		4890.61	Diffuse
2956.34		4929.84	Complex
2963.96	May be *Tb* λ 2963.98	4934.12	Blend *Ba*
3007.10	May be *Tb* λ 3007.11	4952.469	Faint component to violet
3010.129	Appeared as trace in absorption-furnace spectrum	5017.80	Blend band in furnace
		5143.54	Blend air line in spark; may be *Gd* II
3089.59	May be *Tb* λ 3089.58		
3119.59	May be *Tb* λ 3119.62	5162.47	Red component stronger
3219.98	May be *Tb* λ 3219.95	5252.14	Furnace line measured λ 5252.127
3256.34	Blend λ 3256.377	5357.59	Blend *Eu* in arc
3422.353	Furnace λ; blend λ 3422.466 in arc	5439.54	Complex
3425.001	Furnace λ; arc line may be blend *Eu* II	5476.29	Shaded to red
		5525.61	May be *Tb*
3444.577	May be *Tb* λ 3444.58	5548.20	Arc has fainter component to violet
3564.924	Furnace λ; blend ghost in arc	5588.95	Violet component stronger; may be band line in furnace
3545.68	In wing of λ 3545.797		
3592.709	Violet component stronger	5591.85	Red component stronger
4092.713	Blend *V* in furnace	5593.29	May be band line in furnace
4157.784	Red component faint	5626.04	Furnace line may be *V*
4197.681	Red component stronger	5689.48	Furnace line may be *Ti*

NOTES TO TABLE 2—*Continued*

5727.68	Blend *V* in furnace	6291.29	Furnace λ; partly *Eu*
5807.59, 5807.72	Not resolved	6371.64	Blend band line in furnace
		6563.70	Masked in spark by *Hα*
5992.91	Blend *Eu* in arc	6368.00	Masked in spark by *Hα*
6001.03	Blend λ 6000.96	6633.32	Blend *V* in furnace
6049.50	Blend *Eu*	6802.68	Blend *Eu*
6182.69	May be line blended with band head	6950.35	May be *Dy*
6258.45	Blend band line	7301.22	Blend *Eu*
6259.87	Blend band line	7432.57	Faint component to red
6289.68	Furnace λ; blend λ 6289.73 in arc		

TABLE 3

GADOLINIUM LINES PHOTOGRAPHED WITH 1-METER CONCAVE GRATING, PROBABLY *Gd* I
(λλ 9290–10677)

λ	Arc Int.	λ	Arc Int.
9290.46	40	10151.47	20
9306.07	10	10161.31	100
9730.52	50	10179.6	5
9816.5	10	10219.68	80
9898.72	150	10284.01	10
9930.58	200	10321.89	5
9959.00	80	10324.33	20
9964.7	8	10364.56	8
9981.9	4	10505.40	20
10001.1	5	10510.90	5
10008.73	15	10622.2	2
10034.74	40	10629.1	6
10063.49	10	10677.2	10

TABLE 4

Gd II LINES IN THE SOLAR SPECTRUM

ARC		SUN			REMARKS
λ	Int.	λ	Ident.	Int.	
2999.045	8000	036	*Gd* II	−3	
3010.129	8000	177	*Fe, Fe* II	0	Masked
3027.602	8000	613	*V* II, *Gd* II	0	
3032.845	10000	868	*Gd* II	−3	
3034.051	8000	063	*Cr* II, *Gd* II	−1	
3068.643	4000	599	*OH*	1	Absent
3081.993	8000	2.036	*OH, V*	1	Masked
3100.504	10000	525	*Gd* II*	−2	
3223.740	1000?	745	*OH* ?, *Gd* II ?	−2	
3331.383	4000	398	*Gd* II	−2	
3350.474	10000	516	*Ti, Ti* II	2	Masked
3358.620	8000	638	*Co* II, *NH, Gd* II	−1	
3362.233	10000	269	*Cr, NH, Fe*	2d?	Masked
3392.530	2000	499	−*Gd* II	−1N	
3399.991	1200	0.020	*Gd* II	−3N	
3418.733	2000	733	*Gd* II	−2N	
3422.466	10000	497	*Fe*	4	Masked
3422.592	1200	600	*Gd* II	−2	
3439.208	3000	230	*Gd* II	−2N	
3439.990	6000	0.003	*Gd* II	−2N	
3450.376	4000	335	*Fe*	5	Masked
3454.904	2000	925	*Gd* II	−3	
3463.984	5000	980	*Fe* II	2	Masked
3467.267	3500	273	*Ti*	−1	Masked
3468.989	3000	980	*Co*	0	Masked
3473.219	2000	228	*Gd* II	−3	
3481.275	5000	302	*Cr*	0	Masked?
3481.797	3000	815	*Gd* II	−1	
3494.404	3000	413	*Gd* II	−3	
3545.797	3000	830	*Fe–CN*	3	Masked
3549.365	3000	372	*CN, Gd* II*	0	
3557.053	1000	065	*Cd* II ?	−3	
3584.962	3000	966	*Fe*	6	Masked
3646.19	3000	197	*Ti–Gd* II*	1	
3671.20	1500	223	*V–Gd* II?*	−2	
3687.74	800	761	*Gd* II?	−3	
3697.73	1000	748	*Gd* II	−2	
3699.73	800	741	*Gd* II?	−2	
3712.70	2000	718	*Gd* II	−2	
3719.45	800	460	*Gd* II?*	−2N	
3768.38	2000	408	*Gd* II*	0	
3796.37	2500	393	*Gd* II	0	
3813.97	2000	4.014	*Cr* II, *Gd* II	0	
3894.696	2000	715	*Mn, Gd* II	0	
3902.398	1000	432	*Gd* II −	1	
3916.508	3000	523	*Gd* II	−1	
4049.429	1200	442	*Mn, Gd* II*	−1	
4049.858	2000	871	*Fe–Gd* II*	−1	
4063.390	1500	426	*Gd* II	0	
4085.564	2000	579	*Gd* II*	−1	
4098.606	3000	596	−*Gd* II ?	2	
4130.372	3000	370	*Gd* II*	−1	

* "*Gd*+?" in *Revised Rowland*.

TABLE 4—*Continued*

Arc		Sun			Remarks
λ	Int	λ	Ident.	Int.	
4132.275	2000	285	*Gd* II—	0N	
4212.014	800	043	*Gd* II, *Fe*	−1N	
4251.733	2000	751	*Gd* II, *Ti**	−1	
4253.366	800	368	*Gd* II, *Ce* II	−1	
4280.490	1500	496	*Gd* II	−2	
4296.076	1000	078	*La* II, *V*, *Gd* II	0N	
4316.052	600	087	*Gd* II?—	−1N	
4330.606	600	583	*Gd* II?	−2	
4342.179	1500	192	*Gd* II*	0	

DWARF M STARS FOUND SPECTROPHOTOMETRICALLY

FIRST LIST

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ABSTRACT

Table 1 lists 82 dwarf M stars detected, without previous knowledge of their motions, by their appearance on the McCormick objective prism plates. Proper motions for 79 of these stars are given.

The mean absolute magnitude of the dM0 stars is found to be 8.4, while for the dM2 stars it is 9.9. These values are in good agreement with those found for the corresponding classes at Mount Wilson.

Data concerning the velocity ellipsoids are given in Table 3. The ellipsoids are, in fact, very prolate spheroids. The peculiar velocities, as compared with those of the A stars, are consistent with an assumption of equipartition of energy.

Eighteen months ago a preliminary report was made on the possibility of using the McCormick collection of objective prism plates for detecting dwarf M stars without any knowledge of their proper motions.[1] At that time it was planned to determine at this observatory the trigonometric parallaxes of as many of these stars as possible and to discuss the whole material after a good number of new parallaxes was available. However, because of the depleted staff of the observatory, this is now out of the question; and it has been decided to publish the list as it stands, supplementing it with as many proper motions as possible. This has involved the determination of 23 new proper motions.

It is hoped that it will be possible to increase the material considerably in the future, so that we shall be able to determine the apex and vertices. In addition, the larger material would be of considerable value in connection with the question of space densities.

Criteria of classification.—A spectrophotometric method of detecting dwarf M stars, suitable for spectra of low dispersion, was discovered by Lindblad several years ago.[2] He pointed out a depression of the continuous spectrum which starts near the *Ca* line, λ 4227, and spreads toward the longer wave lengths. A closer study of his Figures 1 and 2 indicates that the depression is not limited to the vicinity of the *Ca* line but can be traced as far as λ 4400. Consequently, the spectrum of a dM star photographed with low dispersion has the following characteristics: (*a*) the portion of the spectrum immediately to the violet of λ 4227 appears stronger than the portion immediately to the blue; (*b*) the "break" at λ 4310, which is quite pronounced in the spectra of M giants, is smoothed out in the spectra of dwarfs; and (*c*) the intensity of the continuous spectrum from λ 4310 to λ 4700 increases much more rapidly in the spectrum of a dwarf than in the spectrum of a giant.

These "Lindblad characteristics" were discovered independently by the author while he was first establishing the criteria to be used for the general classification of spectra on the McCormick plates.[3] The criteria as finally adopted for the dwarf M stars follow:

dM0 The "Lindblad depression" is noticeable; the G band is very weak or absent; λ 4227 is moderately strong; the *TiO* band at λ 4955 is barely visible.

dM2 The "Lindblad depression" is strong; λ 4227 is very strong; the *TiO* band at λ 4955 is well marked, and the one at λ 4760 is suspected.

[1] *Pub. A.A.S.*, **10**, 176, 1942.

[2] *Stockholms Obs. Ann.*, **12**, No. 2, 1935.

[3] At that time there was no opportunity to pursue the matter further, and the author is indebted to Dr. Rupert Wildt, who called his attention to the fact that Lindblad had already found the same luminosity criteria.

dM5 The "Lindblad depression" tends to break the spectrum in the middle, so that the first glance suggests an overlap of two spectra. Relatively few dM5 stars are bright enough to appear on our plates.

Since this scheme of classification was established by consulting the Mount Wilson catalogue of spectroscopic parallaxes,[4] it is to be expected that our classification will agree with the system of that catalogue. It is not claimed as a very precise luminosity classification. In fact, for underexposed spectra, the general appearance of the spectrum with its characteristic distribution of intensity from λ 4210 to λ 4700 was regarded as sufficient to classify the star as a dwarf M.

The material.—A systematic search for dwarf M stars by this method, and without any knowledge of proper motions, was begun by Mr. C. A. Wirtanen shortly before he left this observatory. He surveyed 30 plates and found 28 dM stars. Since his departure there has been no opportunity to continue any such systematic search or to estimate, by a resurvey of the same plates, the number of dwarfs he may have missed. It is hoped that this may be done in the future. The other 54 stars included in the present list were found accidentally by the author, with few exceptions, while checking the plates or classifying the stars of the McCormick proper-motion programs. If the proper motion or the absolute magnitude of a star was known in advance, it was excluded from the present list. However, there were very few cases of this sort.

The columns of Table 1 are, in the main, self-explanatory. The visual magnitudes are in most cases *Bonner Durchmusterung* magnitudes reduced to International Photovisual.[5] Where these were unavailable, estimates were made by the author. The proper motions have been collected from various sources or measured at this observatory by making use of the *Astrographic Catalogues*. For three stars the proper motions are not as yet available. The trigonometric parallaxes have been taken from the *Yale General Catalogue*[6] or from various recent sources.

The spectral classes published by the Mount Wilson observers[4] and by Kuiper at the McDonald Observatory[7] are listed in the table. Spectra published by Luyten and by the Bergedorf observers are given in the notes to the table, since they are less numerous. No spectra from the *Henry Draper Catalogue* or the *Henry Draper Extension* are quoted, since Miss Cannon did not discriminate between giants and dwarfs.

The table lists 58 new dM stars in addition to the 24 stars which have been known previously. In most cases the classification depends upon a single plate, so that there is some chance of error. Indeed, the fact that there are three stars with motions smaller than $0''.04$ (Nos. 7, 52, and 69) seems to indicate that probably two of these stars are not dwarfs, since we should hardly expect, from a priori considerations, more than one dwarf with such small motion. Accordingly, in the computations involved in the next two sections, two of these stars have been arbitrarily excluded.

Mean absolute magnitudes and parallactic motions.—The list contains 14 stars of class M0 and 13 of class M2 for which trigonometric parallaxes have been determined. If we assume that they constitute representative samples of the absolute magnitudes in the two spectral classes, they may be used for determining the mean absolute magnitudes of the classes as a whole. Accordingly, the probable error of each individual absolute magnitude was computed, taking into account the error in the parallax and that in the apparent magnitude (assumed to be $0^m.3$). The individual absolute magnitudes, weighted in accordance with these probable errors, were then combined to determine the mean value, which appears in Table 2 in the column headed $\overline{M}_{tr}$. The unweighted means are $8^m.3$ and $9^m.7$, respectively.

[4] *Mt. W. Contr.*, No. 511, 1935.

[5] *Ap. J.*, **83**, 216, 1936.

[6] 2d ed.; Yale, 1935.

[7] *Ap. J.*, **87**, 592, 1938; **89**, 548, 1939; **91**, 269, 1940; **92**, 126, 1940; **95**, 201, 1942; **96**, 315, 1942.

TABLE 1

LIST OF DWARF M STARS

No.	BD or AC	1855.0 R.A.	1855.0 Decl.	m_v	μ_α	μ_δ	Spectrum McC	Spectrum MtW	Spectrum McD	π	Source of Proper Motion
1...	+17°112	0h43m7	+17°56′	9.7	+0".019	−0".272	M0	.....	.....	+0".088	Ci 18.112
2*..	+61.195	0 53.4	+61 34	9.0	+ .75	+ .09	M2	.....	M1	.....	Ci 20.68
3...	−11.192	0 55.1	−11 12	10.1	.....	.....	M0	.....	.....	.....	.....
4...	−23.693	1 46.8	−23 3	8.8	+ .857	+ .007	M2	M0	.....	+ .081	Ci 18.251
5...	*+49.2493-285*	2 15.6	+49 8	11.2	+ .167	− .063	M0	.....	.....	.....	McC 379.27
6...	+39.710	2 57.5	+39 48	9.4	− .33	+ .18	M0	.....	.....	.....	Ross 332
7*..	+ 6.525	3 16.8	+ 6 28	9.9	− .031	− .018	M0	.....	.....	.....	McC–AC
8...	+21.652	4 20.4	+21 34	8.9	− .048	+ .222	M0	.....	.....	.....	E.B.–Lex.
9...	− 3.1123	5 24.1	− 3 43	8.7	+ .744	−2.094	M2	M3	M1	+ .168	Ci 18.705
10...	− 6.1339	5 45.9	− 6 1	9.5	+ .004	− .181	M0	.....	.....	.....	McC–AC
11...	*+56.35386*	6 38.0	+56 0	10.5	+ .009	− .214	M0	.....	.....	.....	McC–AC
12...	+12.1343	6 46.8	+12 21	10.2	− .03	− .34	M0	.....	.....	.....	Ross 611
13...	+30.1367a	6 47.7	+30 55	9.5	+ .092	− .215	M0	.....	.....	.....	McC–AC
14...	+27.1311	6 56.7	+27 41	10.6	− .047	− .097	M0	.....	.....	.....	McC–AC
15*..	+59.1056	6 59.6	+59 30	10.0	+ .095	− .290	M0	.....	.....	.....	Radcliffe SA 11
16...	+33.1505	7 10.0	+33 6	9.9	+ .40	− .39	M2	M2	K6+	+ .050	Ci 20.418
17...	+ 5.1668	7 19.6	+ 5 40	10.3	+ .583	−3.694	M5	.....	M4	+ .262	*A.J.* 1129
18...	+14.1802	7 52.1	+14 12	10.3	− .080	− .106	M0	.....	.....	.....	E.B.–Lex.
19...	+44.1710	7 54.2	+44 22	9.8	+ .152	+ .008	M0	.....	.....	.....	Hls. ph. II 968
20*..	−13.2439	8 6.4	−13 28	9.2	− .205	− .458	M0	.....	.....	.....	McC–AC
21...	+14.1876	8 12.8	+14 32	10.4	− .072	− .266	M0	.....	.....	.....	E.B.–Lex.
22...	+22.1921	8 15.0	+22 19	9.8	+ .32	− .22	M0	.....	.....	.....	Ci 18.986
23...	+43.1827	8 24.2	+43 3	9.8	+ .192	− .046	M0	.....	.....	.....	Hls. ph. II 1170
24...	+ 7.2031	8 40.6	+ 7 2	9.8	+ .221	− .415	M0	.....	.....	+ .018	McC 121.37
25...	*+27.23636*	9 0.5	+28 1	9.5	− .205	− .031	M0	.....	.....	.....	McC–AC
26...	−12.2918	9 24.3	−12 52	10.3	+ .76	+ .07	M2	.....	M4	+ .099	Ross 440
27...	−11.2741	9 43.9	−11 37	9.8	+1.169	−1.425	M2	M2	.....	+ .079	Ci 18.1167
28*..	+40.2309	10 6.5	+40 13	9.5	+ .046	+ .165	M0	.....	.....	.....	Hls. ph. I 326
29*..	*+40.428-42*	10 6.6	+40 14	10.0	+ .075	+ .148	M2	.....	.....	.....	Hls. ph. I 330
30*..	+56.1458	10 21.1	+56 44	8.6	− .165	− .058	M0	.....	.....	+ .082	Yale zone cat.
31...	+57.1274	10 22.3	+57 51	10.3	− .046	+ .148	M0	.....	.....	.....	McC–AC
32*..	+46.1635	10 22.8	+46 16	9.8	− .580	− .595	M0	M1	K6	+ .048	Hls. ph. I 420
33*..	+39.2376	10 37.0	+39 15	8.5	− .026	+ .123	M2	.....	.....	.....	E.B.–Lex.
34*..	+70.639	10 47.9	+70 22	10.3	− .630	+ .058	M0	.....	M0	+ .042	Green. Ast. C. 4
35...	+44.2051	10 58.2	+44 16	8.6	−4.425	+ .948	M2	M2	M1	+ .174	Ci 18.1349
36*..	*+44.472-15*	11 3.2	+44 12	10.0	− .600	− .444	M2	.....	.....	.....	Hls. ph. I 681
37...	−17.3336 / −17.3337	11 8.1	−17 20	10.4 / 9.5	+ .16	− .80	M0 / M0	.....	K6 / K6	+ .052	Ci 20.621
38*..	+66.717	11 12.5	+66 38	9.4	−2.977	+ .179	M2	M1	M1	+ .120	Ci 18.1383
39...	*+40.477-39*	11 17.0	+40 46	9.4	− .109	− .003	M0	.....	.....	.....	Hls. ph. I 764
40...	*+33.238-107*	11 36.2	+33 22	10.0	+ .020	− .104	M0	.....	.....	.....	McC–AC
41...	+ 4.2612	12 16.8	+ 4 44	10.6	− .022	− .122	M0	.....	.....	.....	McC–AC
42...	+ 0.3077	12 28.0	+ 0 19	9.7	+ .018	+ .191	M0	.....	.....	.....	McC 175.12
43...	− 1.2754	12 52.9	− 1 55	9.4	− .73	.00	M0	M0	K5	+ .061	Ci 18.1661
44...	*+37.30242*	13 11.4	+37 6	10.5	+ .08:	− .32:	M2	.....	.....	.....	McC–AC
45*..	.....	13 12.8	+34 7	10.0	− .30	− .10	M2	.....	.....	.....	Ross 1007
46*..	+35.2436	13 12.8	+35 54	9.5	+ .383	− .797	M2	M1	.....	+ .086	Ci 18.1719
47...	+35.2439	13 14.2	+35 3	10.8	+ .48	− .29	M0	.....	.....	.....	Ross 1008
48...	+ 5.2767	13 27.0	+ 5 25	9.2	+ .13	− .16	M0	.....	.....	.....	Wolf 1487
49...	+36.2393	13 30.9	+36 28	8.7	+ .340	− .061	M2	.....	.....	.....	E.B.–Lex.
50...	+ 0.3090	13 34.5	+ 0 36	9.2	− .15	− .39	M0	M1	.....	.....	Ci 20.795
51...	− 3.3527	13 37.6	− 3 53	10.8	− .161	− .064	M2	.....	.....	.....	McC–AC
52*..	*+3.2448-85*	13 37.8	+ 2 51	10.5	− .002	+ .013	M0	.....	.....	.....	McC–AC
53...	+13.2721	13 46.4	+13 40	9.9	− .23	− .71	M0	.....	.....	.....	Ci 20.821
54*..	+45.2147	13 54.4	+45 31	10.1	− .186	+ .013	M0	.....	.....	.....	McC–AC
55...	−10.4011	14 52.9	−10 33	9.9	+ .028	− .466	M0	M0	.....	+ .053	Ci 18.1989
56...	*+45.630-70*	14 54.2	+46 1	10.0	− .033	+ .118	M0	.....	.....	.....	McC–AC
57*..	+25.2874	15 1.2	+25 29	9.8	− .824	+ .491	M0	M0	.....	+ .077	Ci 18.2012
58...	− 4.3873	15 14.5	− 4 15	9.3	− .289	+ .003	M0	.....	.....	.....	McC–AC
59...	+35.2774	16 1.2	+35 3	10.6	+ .26	− .59	M0	M0	.....	+ .046	Ci 20.968
60...	*+33.276-33*	17 14.7	+33 15	10.0	− .13	.00	M0	.....	.....	.....	Wolf 688
61*..	+29.3029	17 23.7	+29 31	9.3	− .26	− .29	M0	.....	.....	+ .055	Ci 2334
62*..	*+61.26806*	17 34.0	+61 47	10.3	+ .235	− .525	M2	.....	.....	+ .095	*Pub. A.S.P.*, **33**, 319
63...	− 1.3474	18 12.3	− 1 59	10.3	.....	.....	M2	.....	.....	.....	.....
64...	*+3.2528-176*	18 42.8	+ 2 55	10.0	− .12	− .44	M2	.....	.....	+ .078	Ci 20.1111
65*..	+ 4.4048	19 9.9	+ 4 58	9.4	− .59	−1.33	M2	.....	M3	+ .170	Wolf 1055

TABLE 1—*Continued*

No.	BD or AC	1855.0		m_v	μ_α	μ_δ	Spectrum			π	Source of Proper Motion
		R.A.	Decl.				McC	MtW	McD		
66...	+77°767	20h15m6	+77°16′	10.7	+0".181	+0".016	M0	.....	.....	+0".017	McC 704.16
67...	+26.3915	20 24.1	+26 22	10.4	− .154	− .132	M2	.....	.....	.....	McC–AC
68...	+56.2471	20 37.9	+56 54	10.5	+ .096	+ .202	M0	.....	.....	.....	McC 724.1
69*..	+10.4409	20 48.3	+10 43	8.9	− .014	− .024	M0	.....	.....	.....	McC–AC
70...	*+3.2561-36*	21 19.4	+ 3 6	10.2	− .075	− .062	M2	.....	.....	.....	McC–AC
71...	+40.4631	21 38.7	+40 56	10.0	− .049	+ .061	M0	.....	.....	.....	McC–AC
72*..	*+41.915-440*	21 48.0	+41 9	10.5	+ .381	− .369	M0	.....	.....	+ .083	Furuhj. 57
73...	− 5.5715	22 2.0	− 5 22	10.8	+ .80	.00	M2	.....	M4	+ .118	Wolf 1329
74*..	*+18.1937-307*	22 4.4	+17 42	10.0	+ .342	+ .202	M2	.....	.....	.....	McC–AC
75...	+21.4747	22 17.9	+21 50	9.1	− .188	− .070	M0	.....	.....	.....	Yale zone cat.
76...	*+44.955-266*	22 39.4	+44 38	10.0	+ .40	− .04	M0	.....	K4	+ .033	Ross 223
77...	+65.1846	22 58.8	+65 59	9.8	+ .304	− .079	M2	.....	.....	.....	McC–AC
78...	− 2.5958	23 19.6	− 2 5	11.1	+ .395	+ .249	M2	.....	.....	.....	McC–AC
79...	+15.4829	23 21.1	+15 16	9.4	.....	.....	M0	.....	.....	.....	.....
80*..	+19.5116	23 24.5	+19 8	10.1	+ .523	+ .004	M0e	.....	.....	.....	McC–AC
81...	+ 0.5017	23 27.6	+ 0 48	9.9	+ .340	+ .045	M0	.....	.....	.....	McC–AC
82...	+ 1.4774	23 41.6	+ 1 37	8.7	+1.000	−0.969	M2	M2	M2	+0.167	Ci 18.3124

NOTES TO TABLE 1

McC–AC denotes a motion derived by comparing a recent McCormick plate with the AC position; McC followed by a number denotes a star in the general proper motion program of this observatory.

2. Luyten (*Lick Obs. Bull.*, No. 351): Ma; Popper (*Ap. J.*, **95,** 307, 1942) notes emission in H and K lines; McCormick plates do not show it; Bergedorf: dMc.
7. Possibly not a dwarf; see text.
15. Bergedorf: g: K2.
20. Luyten (*Pub. Obs. Minnesota*, **3,** 1, 1941): proper motion = 0".52 in 205°.
28, 29. Moving pair.
30. One of the companions of 36 UMa (*Pub. A.S.P.*, **54,** 263, 1942); parallax assumed the same as 36 UMa.
32. Luyten (*Lick Obs. Bull.*, No. 351): K0.
33. ADS 7915, 9m–12m, 1".
34. Luyten (*Lick Obs. Bull.*, No. 351): K5.
36. The declination as originally published by Furuhjelm was in error by 2° (*Ap. J.*, **97,** 77, 1943); Kuiper (private letter) finds it a close double with $d = 4''$.
38. SZ UMa; variability doubtful.
45. Not in AC Potsdam.
46. ADS 8861, 9m–10m, 17".5.
52. Possibly not a dwarf; see text.
54. Bergedorf: g: : M0.
57. Luyten (*Lick Obs. Bull.*, No. 351): K0.
61. ADS 10585, 9m.5–9m.9, 0".5; the spectrum A3 given there belongs to BD+29°.3028.
62. Companion to 26 Dra; Luyten (*Lick Obs. Bull.*, No. 351): Ma.
65. Luyten (*Harvard Circ.*, No. 283): Ma.
69. Possibly not a dwarf; see text.
72. Luyten (*Lick Obs. Bull.*, No. 344): Ma.
74. This is Ross 271; Kuiper writes that the spectrum published by him (*Ap. J.*, **87,** 592, 1938) belongs to a near-by field star.
80. Wirtanen (*Pub. A.S.P.*, **53,** 340, 1941) found a companion of 12m, 3".5; Humason and Joy (private letter) observed emission in both components.

TABLE 2

Class	$\overline{M}_{tr}$	No. of Stars	$\overline{\left(\frac{h}{r}\right)}$	$\overline{M}_{pm}$	No. of Stars
M0.....	8.7±0.1	14	0".182±0".023	8.1±0.3	50
M2.....	9.9±0.1	13	0.418±0.082	9.9±0.4	26

It is of interest to see how well these values agree with the values inferred from the parallactic motions. For this purpose each of the proper motions has been reduced to the corresponding proper motion of a tenth-magnitude star by means of the relation

$$\text{Reduced proper motion} = 10^{0.2m-2} \times \text{Observed proper motion} .$$

The upsilon component was computed with the aid of Smart's charts,[8] which assume the apex at 18^h, $+34°$. As explained in the preceding section, stars numbered 52 and 69 were omitted. The resulting secular parallaxes $\left(\overline{\frac{h}{r}}\right)$ are given in Table 2. To obtain the corresponding values of the mean absolute magnitudes, a solar velocity of 20 km/sec has been assumed in accordance with the value determined by Nordström[9] from the radial velocities of 241 dwarf K and M stars. Furthermore, a value of 0^m6 has been assumed for the standard deviation among the individual values of the absolute magnitude in each of the groups. The results are given in the column headed $\overline{M}_{pm}$ of Table 2. The agreement of these with the values in the second column is satisfactory.

By consulting Figure 1 in *Mt. Wilson Contr.* No. 511, we find that our subclasses agree closely in luminosity with those of Mount Wilson, as would be expected. On the other hand, our classes M0 and M2 correspond to K6 and M1+ on the Morgan-Kuiper system.[10] This is not surprising, in view of the fact that the Morgan-Kuiper classification uses a different set of criteria, which lie chiefly in the red portion of the spectrum.

Velocity ellipsoid.—The derivation of the velocity ellipsoid for dwarf stars has heretofore been subject to considerable uncertainty because the stars had been selected by means of their proper motions. In particular, this affected the *b*-axis, since it lies within 40° of the direction of the solar motion. Although the present material is not large, the proper motions are relatively well determined, nearly all being larger than 0".1. With such limited material it seemed best to assume the directions of the axes, the following positions of the vertices being adopted:

Axis	l	b	α	δ
a	330°	0°	17^h40^m	−26°
b	60	0	21 16	+50
c	.....	90	12 40	+28

The dispersion along each axis has been computed for the M0 and M2 stars separately.

The method of computation is analogous to the one suggested by Strömberg[11] for use when the number of available radial velocities is small.[12] He restricted the material for the determination of any one axis to stars lying within 45° of either vertex. In the present case of proper motions, on the other hand, the material for the determination of any one axis is restricted to stars lying more than 60° from either vertex. The method may be most readily explained for the case of the *c*-axis, since it is directed toward the galactic poles. As before, the proper motions have been "reduced to tenth magnitude" and stars number 52 and 69 omitted. For each star within 30° of the galactic equator the parallactic motion was subtracted from the proper motion. Then the peculiar motion directed toward the *c*-vertex was computed. This is denoted as μ_c; it is also, in this case,

[8] London: Royal Astronomical Society, 1923.

[9] *Medd. Lunds Astr. Obs.*, Ser. II, No. 79, 1936.

[10] *Ap. J.*, **87**, 589, 1938.

[11] *Mt. W. Contr.*, No. 293, 1925.

[12] I am indebted to Dr. E. T. R. Williams for suggesting this method to me.

the peculiar motion in galactic latitude. The square of the mean value of these without regard to sign, multiplied by $\pi/2$, is denoted by c'^2. The values of a'^2 and b'^2 are computed in a similar manner but using different sets of stars. Thus,[13]

$$a'^2 = \frac{\pi}{2}\bar{\mu}_a^2,$$

$$b'^2 = \frac{\pi}{2}\bar{\mu}_b^2,$$

$$c'^2 = \frac{\pi}{2}\bar{\mu}_c^2.$$

These are approximately the squares of the dispersions along the axes, but they are systematically slightly in error. To determine the corrections, we note that the square of the dispersion in any particular direction is

$$\sigma^2 = a^2\gamma_1^2 + b^2\gamma_2^2 + c^2\gamma_3^2.$$

Here a, b, and c are the true dispersions along the axes; and γ_1, γ_2, and γ_3 are the direction cosines. Now, c'^2 is the average value of σ^2 throughout the equatorial belt; consequently, we compute average values of the direction cosines over the same area. In the case of the c-axis this is for stars between $-q°$ and $+q°$. We find

$$\overline{\gamma_3^2} = 1 - \tfrac{1}{3}\sin^2 q = Q,$$

$$\overline{\gamma_1^2} = \overline{\gamma_2^2} = \frac{1-Q}{2}.$$

Thus,

$$c'^2 = Qc^2 + (1-Q)\frac{a^2+b^2}{2}.$$

Similarly,

$$a'^2 = Qa^2 + (1-Q)\frac{b^2+c^2}{2},$$

$$b'^2 = Qb^2 + (1-Q)\frac{a^2+c^2}{2}.$$

Solving these equations and setting q equal to 30°, we have

$$c^2 = 1.095\,c'^2 - 0.048\,(a'^2 + b'^2),$$

and similarly for a^2 and b^2.

The results are given in Table 3. Here $\bar{\mu}_a$, $\bar{\mu}_b$, and $\bar{\mu}_c$ are expressed in seconds of arc; but the values of a, b, and c are given in kilometers per second, assuming a mean absolute magnitude of 8.4 for the M0 stars and 9.9 for the M2 stars. The figures in parentheses indicate the number of stars used for each axis. Thus it is seen that the probable errors of the values of $\bar{\mu}$ for the M0 stars average about 10 per cent, and those for the M2 stars about 15 per cent.

Dynamical considerations.—Perhaps the most striking feature of Table 3 is the fact that the b-axis is of about the same size as the c-axis. Heretofore, in previous derivations of the velocity ellipsoid for dwarfs, the b-axis has been intermediate in size between the a- and c-axes. This can now be ascribed with some confidence to the effect of the selection of

[13] By $\bar{\mu}$ we denote the mean value without regard to sign.

the material, as suggested at the beginning of the last section. It now appears probable that the velocity ellipsoid is a prolate spheroid for all stars of the main sequence as well as for the giants.

However, the ellipsoids of Table 3 are very much more prolate than the ellipsoids of the giants, the ratio of the short diameter to the long being 0.45 for these M dwarfs, as compared with 0.70, approximately, for the giants. In the case of the A stars, the ratio is about 0.60; but this may be somewhat too large, since all the axes are small and the effect of the errors of observation, in particular the effect of undetected spectroscopic binaries, will be greater on the smaller axes.

It is also significant that within the errors of observation the peculiar velocities of the M dwarfs relative to those of the A stars are consistent with an assumption of equiparti-

TABLE 3

	dM0	dM2		dM0	dM2
$\bar{\mu}_a$	0".258 (24)	0".600 (20)	a	33 km/sec	39 km/sec
$\bar{\mu}_b$	.147 (31)	.272 (13)	b	17	15
$\bar{\mu}_c$	0.123 (20)	0.279 (9)	c	14	16

tion of energy, whereas the stars of the giant sequence exhibit several times as much kinetic energy. This is in line with current astrophysical conjectures as to the different origin of giants and main-sequence stars, since the mechanism of generation of internal energy for the stars points to a different time scale in the two cases.

The much larger kinetic energy and the relatively large c-axis of the giants are connected with their space distribution perpendicular to the galactic plane, it being well known that their observed density gradients are low. However, if equipartition of energy obtains for the main-sequence stars, we may expect that the density gradient, $(\Delta \log D)/\Delta z$, for the G dwarfs, say, would be related to the observed density gradient of the A stars by an "atmospheric" formula, thus:

$$\frac{\text{Density gradient for dG stars}}{\text{Density gradient for A stars}} = \frac{\text{Average mass of dG star}}{\text{Average mass of A star}}.$$

If this relationship is valid, then the density gradients computed thereby for the G and K dwarfs would be steeper than the observed density gradients for the G and K giants. Observational evidence confirming this was obtained a few years ago,[14] at which time the matter was regarded as rather puzzling.

[14] *Pub. McCormick Obs.*, **7**, 17, 1937.

THE SHELL SPECTRUM OF HR 8731 IN 1940, WITH AN INTERCOMPARISON OF THE SPECTRA OF SEVERAL SHELLS

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ABSTRACT

The 1940 shell spectrum of HR 8731 was very similar to that of ζ Tauri in 1914. This paper presents an analysis of the spectrum in which lines of *H*, *O* I, *Mg* I, *Mg* II, *Si* II, *Ca* I, *Ca* II, *Ti* II, *Cr* II, *Fe* I, *Fe* II, *Sr* II, *Sc* II, and *Ni* II were identified. It is suggested that HR 8731 may be the brighter component of a long-period binary.

When the shell spectra of γ Cassiopeiae, ζ Tauri, ϵ Capricorni, β Monocerotis, Pleione, HR 8731, and ψ Persei are compared it is found that they can be arranged, as above, in order of decreasing excitation conditions in the shell. The primary difference between various shells is one of ionization rather than composition. Usually the cooler shells contain less material, i.e., the shell absorption lines are weak.

In October, 1921, three spectrograms of HR 8731[1] were obtained with the one-prism spectrograph on the 37½-inch reflector of the Observatory of the University of Michigan. The spectrum appeared to be that of a normal B3e star—no trace of a shell spectrum was present.

No more plates were taken until August, 1928, when a fully developed shell absorption spectrum was noted. In many respects it was similar to that of ζ Tauri in 1914.[2] This set of shell lines has persisted until today, possibly with increasing strength.

This paper contains an analysis of the shell lines as of November 15, 1940. The spectrogram described was taken on Process emulsion. Reality of the weaker lines was checked on a spectrocomparator against other spectrograms taken near this date.

Lines of hydrogen were visible to H_{30}. Lines of the singly ionized elements, *Fe* II, *Cr* II, *Ti* II, *Sr* II, *Ca* II, *Si* II, *Ni* II, *Mg* II, and *Sc* II, were numerous, while the lines of the neutral elements, *Ca* I, *Mg* I, *O* I, and *Fe* I, were present. As in ζ Tauri the *Si* II lines were wider than the true shell lines and *Mg* II 4481 was very broad, although not as wide as the photospheric line *He* I 4472. This is the well-known effect of stratification in the atmosphere of a rotating star and the resultant range-of-dilution factor.

The *Mg* I triplet lines near $H\eta$ all seemed to be present, implying that they were produced relatively low in the shell. Several *Fe* I lines were weak but present, and all arose from metastable lower levels.

It is barely possible that *He* I 3965 was visible, although λ 3889 did not seem appreciably stronger than it would be if $H\zeta$ were alone and unblended with *He* I 3888. If the triplet line were missing, the singlet certainly was not present. Table 1 summarizes the results of the investigation.

Radial velocities in the period 1921–1940 suggest that HR 8731 may be the brighter component of a binary with a range of at least 22 km/sec and a period of at least nineteen years. Detailed measured velocities will be published later.

Detailed analyses of the spectra of three shell stars, γ Cassiopeiae in 1940,[3] ζ Tauri in 1914,[4] and HR 8731 in 1940, have now been published. Numerous similarities and sever-

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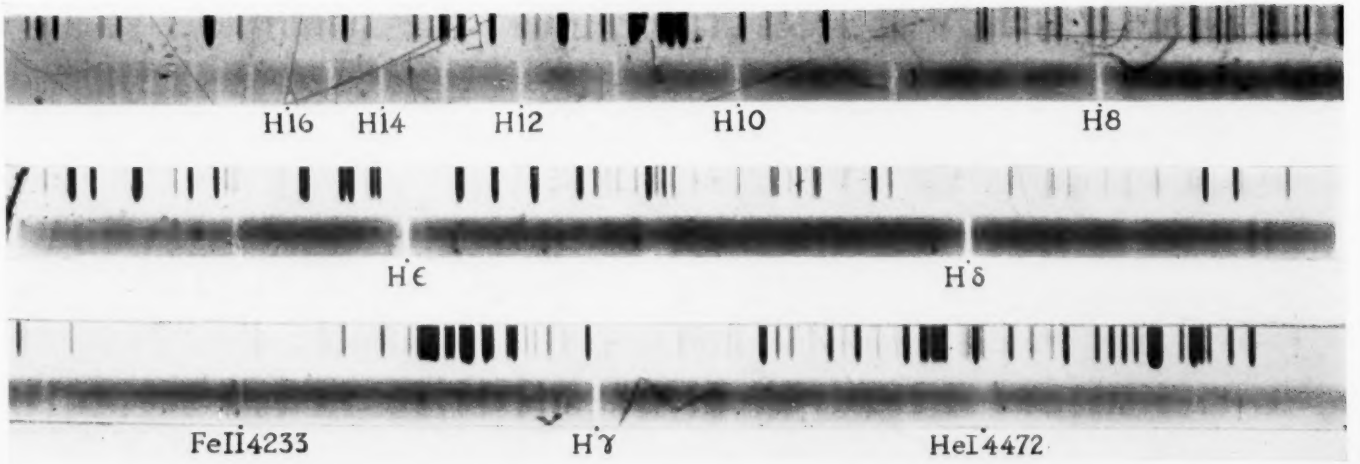
[1] HD 217050 = MWC 394 = BD 47°3985; $\alpha = 22^h52^m7$, $\delta = +48°9'$ [1900]; Sp. B3ne; mag. 5.2.

[2] Baldwin, *Ap. J.*, **93**, 420, 1941.

[3] Baldwin, *Ap. J.*, **93**, 333, 1941.

[4] Baldwin, *Ap. J.*, **93**, 420, 1941.

PLATE XXVIII



THE SPECTRUM OF HR 8731 IN NOVEMBER, 1940

TABLE 1

SHELL ABSORPTION LINES IN HR 8731

Meas. λ I.A.	Int	Identification			N	Meas. λ I.A.	Int.	Identification			N
3662.55	0	H30	2.26	(-)		3859.94	1	ξ Tauri			
63.49	1	H29	3.40	(-)	–			γ Cassiopeiae			
64.64	2	H28	4.68	(-)		62.61	2	Si_{II}	2.60	(6)	
66.01	2	H27	6.10	(-)		65.70	0	Cr_{II}	5.65	(1)	f
67.86	3	H26	7.68	(-)		68.64	0	Cr_{II}	8.32	(2)	
69.47	3	H25	9.47	(-)		72.11	2	ξ Tauri?			
71.36	3	H24	1.48	(-)		74.48	0	ξ Tauri			
73.78	3	H23	3.76	(-)		78.48	3				
76.31	3	H22	6.36	(-)		82.52	0				
77.62	0	Cr_{II}	7.70	(2)	b	84.74	0	ξ Tauri			
			7.86	(4)	a	86.04	0				
			7.93	(2)	b	88.96	20	H8	9.05	(4)	g
79.29	3	H21	9.36	(-)		95.95	1	ξ Tauri?			
82.71	4	H20	2.81	(-)		3900.26	1	Ti_{II}	0.54	(70)	
84.02	0					03.03	2	ξ Tauri?			
85.06	0	Ti_{II}	5.20	(250)		05.94	2	Fe_{II}	6.04	(5)	
86.77	4	H19	6.83	(-)		13.85	1	Ti_{II}	3.47	(60)	a,f
91.53	4	H18	1.56	(-)				Fe_{II}	4.48	(2)	b
97.12	4	H17	7.15	(-)		27.84	0	Fe_{I}	7.92	(30)	e
99.84	0?							ξ Tauri?			
3703.84	5	H16	3.86	(-)				γ Cassiopeiae?			
08.08	0?	Fe_{I}	7.93	(8)	e	29.95	0	Fe_{II}	0.31	(8)	
09.52	0					33.68	6	Ca_{II}	3.68	(400)	K
11.89	5	H15	1.97	(-)		38.48	1	Fe_{II}	8.29	(2)	b
15.10	0?	Cr_{II}	5.18	(2)	b				8.97	(4)	a
			5.40	(2)	b	45.06	0	Cr_{II}	5.11	(1)	b
16.77	0?							Fe_{II}	5.23	(1)	b
20.30	0					47.37	2	O_{I}	7.33	(10)	a
21.88	6	H14	1.94	(-)					7.51	(7)	b
31.99	0?								7.61	(4)	c
34.29	7	H13	4.37	(-)		61.29	1	Fe_{II}	0.90	(3)	
41.65	0	Ti_{II}	1.65	(50)		68.34	3	Ca_{II}	8.49	(350)	H
45.69	1	ξ Tauri				70.06	20	H7	0.08	(5)	
46.68	0					73.87	1	Fe_{II}	4.16	(3)	
48.34	1	Fe_{II}	8.49	(8)		81.68	1				
50.09	8	H12	0.15	(0)		4002.67	1	Fe_{II}	2.07	(2)	c,f
57.61	0	Ti_{II}	7.69	(30)					2.55	(3)	a
59.41	0	Ti_{II}	9.30	(200)	b	05.44	1?	Fe_{I}	5.26	(25)	
		Fe_{II}	9.46	(6)	a	06.64	0?				
61.50	0	Ti_{II}	1.32	(200)		08.08	0?				
63.78	0	ξ Tauri				12.95	0?	Ti_{II}	2.39	(4)	
69.37	2	Ni_{II}	9.46	(5)		15.48	0	Ni_{II}	5.48	(1)	
70.62	10	H11	0.63	(1)		25.09	2	Fe_{II}	4.55	(5)	h
94.61	1					27.83	1	Ti_{II}	8.35	(7)	
95.70	0?	ξ Tauri				30.51	0				
97.83	12	H10	7.90	(2)		35.48	0	ξ Tauri			
3811.75	0	ξ Tauri				37.15	1	ξ Tauri?			
13.82	1	Fe_{II}	4.12	(4)	f	41.57	0				
29.08	0	Mg_{I}	9.37	(40)	f	45.94	1	Fe_{I}	5.83	(60)	f
31.88	2	ξ Tauri				49.85	0?				
32.96	2	Mg_{I}	2.31	(80)		53.81	2	?			a
35.26	15	H9	5.39	(3)				Ti_{II}	3.83	(3)	c
38.06	1	Mg_{I}	8.30	(100)		57.51	1	?			a
39.07	0?							Fe_{II}	7.46	(2)	c
40.63	2					63.52	1	Fe_{I}	3.61	(45)	f
42.79	0					67.01	3	Ni_{II}	7.04	(3)	
45.00	0	ξ Tauri				71.63	1	Fe_{I}	1.75	(40)	f
		γ Cassiopeiae				77.71	2	Sr_{II}	7.73	(400)	
46.91	0?					82.20	0	ξ Tauri?			
49.52	3	Ni_{II}	9.54	(2)		86.67	0?	ξ Tauri?			
52.98	0?	Si_{II}	3.67	(3)	f			γ Cassiopeiae?			
56.06	3	Si_{II}	6.03	(8)	f	4101.82	20	H6	1.75	(6)	
58.38	0	ξ Tauri				22.93	0	Fe_{II}	2.64	(4)	

a Principal contributor
b Strong component
c Weak component
d Trace
e Identification inadequate or doubtful
f Broad

TABLE 1—*Continued*

Meas. λ I. A.	Int.	Identification			N
4128.29	3	Si_{II}	8.05	(8)	b
		Fe_{II}	8.74	(3)	a
31.08	2	Si_{II}	0.88	(10)	f,i
32.55	1	Fe_{I}	2.07	(25)	
43.88	1	Fe_{I}	3.88	(30)	
50.19	0				
56.05	0?				
60.71	0				
62.09	0				
63.89	0	Ti_{II}	3.66	(40)	
71.85	1	Ti_{II}	1.91	(30)	
73.53	2	Fe_{II}	3.45	(8)	
78.59	3	Fe_{II}	8.86	(8)	f
82.25	0?				
84.19	1	ζ Tauri			
87.43	0				
99.23	2	ζ Tauri			
4202.19	1	Fe_{I}	2.04	(30)	
04.98	0				
15.96	0	Sr_{II}	5.54	(300)	
24.44	0				
26.93	2	Ca_{I}	6.74	(500)	
32.97	4	Fe_{II}	3.17	(11)	
36.54	0	ζ Tauri			
42.33	1	Cr_{II}	2.38	(5)	
47.08	1	Sc_{II}	6.84	(100)	
50.41	0	Fe_{I}	0.80	(25)	
53.52	1	ζ Tauri			f
58.26	0	Fe_{II}	8.16	(3)	f
61.43	1	Cr_{II}	1.94	(2)	
68.08	1				
70.99	0?	Fe_{I}	1.78	(35)	
75.05	1	Cr_{II}	5.56	(1)	
82.24	0	Fe_{I}	2.41	(12)	e
		ζ Tauri?			
84.15	0	Cr_{II}	4.23	(2)	
88.14	0	ζ Tauri?			
90.03	2	Ti_{II}	0.23	(50)	c
		?			a
94.58	0	Ti_{II}	4.05		b
			4.15	(40)	a
		Sc_{II}	4.78	(5)	c
96.52	1	Fe_{II}	6.57	(6)	
4300.05	0?	Ti_{II}	0.06	(60)	
02.85	2	Fe_{II}	3.17	(8)	
05.69	0	Sc_{II}	5.72	(6)	
07.97	1	Ti_{II}	7.91	(40)	b
		Fe_{I}	7.91	(35)	b
12.64	0	Ti_{II}	2.88	(35)	
14.49	2	Sc_{II}	4.09	(30)	c
		Fe_{II}	4.29	(4)	a
		Ti_{II}	4.98	(40)	c
20.58	1	Sc_{II}	0.75	(20)	
25.43	3	Sc_{II}	5.00	(20)	c
		Fe_{I}	5.78	(35)	c
		?			a,f
30.30	0				
37.93		Ti_{II}	7.93	(50)	j
40.39	25	Hδ	0.48	(7)	
43.91	2				k
51.80	3	Fe_{II}	1.76	(9)	
57.24	1	Fe_{II}	7.57	(4)	
62.01	0?	Ni_{II}	2.10	(1)	f

Meas. λ I. A.	Int.	Identification			N
4368.50	1	O_{I}	8.30	(10)	
74.35	2	Sc_{II}	4.47	(30)	
76.40	0	ζ Tauri?			
83.52	2	Fe_{I}	3.56	(45)	
85.54	2	Fe_{II}	5.38	(7)	
91.33	1	γ Cassiopeiae			
95.53	2	Ti_{II}	5.04	(60)	b
		?			a
4400.17	1	Ti_{II}	9.78	(35)	b,f
		Sc_{II}	0.40	(20)	b
04.96	0	Fe_{I}	4.76	(30)	
15.56	0	Fe_{I}	5.56	(20)	
17.45	2	Fe_{II}	6.82	(7)	a
		Ti_{II}	7.72	(40)	b
26.50	0?				f
30.88	0				f
44.56	1	?			b
		Ti_{II}	3.88	(50)	b
51.51	0	Fe_{II}	1.54	(4)	
68.79	1	Ti_{II}	8.50	(50)	
76.12	0	γ Cassiopeiae?			
80.88	3	Mg_{II}	1.14	(100)	f
			1.34		
88.70	0	Fe_{II}	9.18	(4)	
91.84	0	Fe_{II}	1.40	(5)	
4500.67	1	?			a,f
		Ti_{II}	1.28	(40)	c
08.72	2	Fe_{II}	8.28	(8)	
15.31	1	Fe_{II}	5.34	(7)	
19.96	1	Fe_{II}	0.22	(7)	
22.61	1	Fe_{II}	2.63	(9)	
27.71	1	ζ Tauri			
30.10	0?				
34.07	2	Ti_{II}	3.97	(30)	b
		Fe_{II}	4.17	(2)	b
40.27	1	γ Cassiopeiae?			
46.13	0				
49.32	3	Fe_{II}	9.21	(4)	c,f
			9.47	(10)	a
		Ti_{II}	9.62	(60)	c
			9.64	(60)	c
52.20	0				
55.08	1	Cr_{II}	4.95	(3)	b
		Fe_{II}	5.89	(8)	a
58.90	0	Cr_{II}	8.65	(20)	f
64.35	2	?			a,f
		Ti_{II}	3.77	(30)	c
67.81	0?				
71.96	1	Ti_{II}	1.98	(50)	
76.18	0?	Fe_{II}	6.33	(4)	
79.87	1	?			a
		Fe_{II}	9.52	(1)	c
83.91	2	Fe_{II}	3.83	(11)	
88.48	0	Cr_{II}	8.21	(15)	
4612.81	0				f
18.79	1	Cr_{II}	8.79	(10)	
29.03	1	Fe_{II}	9.34	(7)	
34.24	2	Cr_{II}	4.08	(10)	c
		Fe_{II}	5.33	(5)	a
57.02	1	Fe_{II}	6.97	(1)	
89.92	1				
4861.61	20	Hβ	1.34	(8)	

g Possibly blended with *He* I 3888
h Blended with broad *He* I 4026
i Sharper than *Mg* II 4481
j Lost in $H\gamma$ but must be present
k Part of $H\gamma$ wing?

al striking differences have been noticed. In addition, spectra of other similar stars ψ Persei, β Monocerotis, ϵ Capricorni, and Pleione, have been examined.

The shells of this group of stars are essentially static. The measured radial velocities are predominantly negative, and yet the dilution factor does not change with time; hence the atoms slowly stream outward through levels where the different absorption lines are produced.

The lines of *Mg* II and *Si* II are not true shell lines, as they appear to be rather broad and are produced in lower atmospheric levels where conservation of angular momentum has not made the rotational velocity negligible. In all cases the shells appear to be of comparable type and composition, differing mainly in the degree of excitation.

For each star, eye estimates of intensities of absorption lines have been made. For interesting lines these have been checked by means of a spectrocomparator. It is felt that the estimated intensities for lines of all stars are essentially on the same scale and hence may be intercompared.

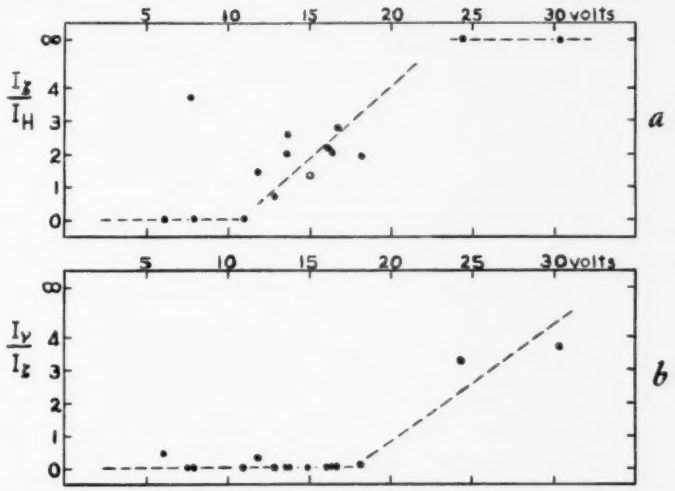


FIG. 1.—(*a*) Intensity ratio of lines of individual elements in the spectrum of ζ Tauri relative to the intensities of the same lines in the spectrum of HR 8731 plotted for each element against the ionization potential of that element. (*b*) Similar intercomparison of lines in the spectrum of γ Cassiopeiae relative to the same lines in ζ Tauri.

The only major difference between the spectra of HR 8731 and ζ Tauri is that the latter represents a higher state of excitation. This is best illustrated in the following manner: For each star the average intensity of the shell absorption lines, which appeared in both spectra, was taken for each element. The ratio of the averages was next found for each element in the sense, line-intensity average in ζ Tauri divided by line-intensity average in HR 8731. The resultant ratio is plotted against the ionization potential of the element in Figure 1, *a* and both are listed in Table 2.

It is seen that elements of low ionization potential give stronger lines, or are present only in HR 8731, and that lines of the element of relatively high ionization potential are enhanced in ζ Tauri.[5]

The lines of *Mg* I are much too strong in ζ Tauri relative to HR 8731, but it is surprising to find them in either spectrum, judging from the excitation conditions shown

[5] The author's scale of estimated absorption-line intensities is nearly linear relative to measured equivalent widths up to intensity 10—stronger than any line in the above discussion. A sharp shell absorption line of intensity 10 is of approximately 0.9 A equivalent width.

by the other elements. Possibly their identifications in most of these stars are incorrect.[6]

A similar comparison may be made between ζ Tauri and γ Cassiopeiae. The latter is very much hotter. The results are shown in Table 3 and Figure 1, *b*.

Table 4 sums up the salient features of the spectra of all seven stars. Column 1 lists their names; columns 2, 3, and 4 show the relative strengths of *Fe* III, *Fe* II, and *Fe* I, as judged from numerous lines. The stars are arranged in this table in order of decreasing excitation, as shown by the iron lines. In the fifth column are the estimated intensities of

TABLE 2*

COMPARISON OF HR 8731 AND ζ TAURI

Element	Ionization Potential	Intensity Ratio	No. of Lines Involved	Element	Ionization Potential	Intensity Ratio	No. of Lines Involved
Ca I	6.09	0	1	*Ti* II	13.6	2.6	18
Mg I	7.61	3.7	3	*Mg* II	14.97	(1.3)	1
Fe I	7.83	0	7	*Fe* II	16.16	2.2	30
Sr II	10.98	0	2	*Si* II	16.27	2.1	4
Ca II	11.82	1.4	2	*Cr* II	16.6	2.8	11
Sc II	12.80	0.7	3	*Ni* II	18.19	1.9	4
H	13.54	.....	27	*He* I	24.41	∞	3
O I	13.56	2.0	2	*Fe* III	30.3	∞	4

* No lines of *Ca* I, *Fe* I, and *Sr* II were found in the spectrum of ζ Tauri; no lines of *He* I and *Fe* III were found in the spectrum of HR 8731. The hydrogen lines are stronger in the ζ Tauri spectrum than in HR 8731, but in both cases they were too strong to have eye estimates of intensity mean much.

TABLE 3*

COMPARISON OF γ CASSIOPEIAE AND ζ TAURI

Element	Ionization Potential	Intensity Ratio	No. of Lines Involved
Mg I	6.09	0.4	2
Ca II	11.82	0.3	2
Ni II	18.19	0.1	2
He I	24.41	3.3	3
Fe III	30.3	3.7	4

* No other elements were positively identified in the spectrum of γ Cassiopeiae except hydrogen, which was strong but not as strong as in ζ Tauri.

the neutral helium singlet, λ 3965, which arises from a metastable lower level. The progression of intensities is in the same direction as that shown by the iron lines. In column 6 is the *O* I line, λ 3947, while the *Mg* I triplet lines are found in columns 7, 8, and 9. The H and K line intensities are in columns 10 and 11, while *Ca* I 4226 is in column 12. Column 13 lists the estimated intensities of *Mg* II 4481, a line of intermediate width. In the last column is the accepted spectral class for the reversing layer of each star. All are broad-line stars.

The star γ Cassiopeiae has by far the hottest of the shells. The lines of *O* I, *Mg* II, and *Ca* I do not appear, while the H and K lines of *Ca* II are greatly weakened. Strangely enough, the latter seem to decrease in strength as the state of excitation decreases down

[6] Lines of *Sc* II were not identified in the 1914 shell spectrum of ζ Tauri (*Ap. J.*, **93**, 420, 1941), as λ 4247 was not found. A re-examination of the two plates discussed shows that in both cases a defect partially obliterates the *Sc* II line. Several *Sc* II lines are weak but present.

the column, but it should be noticed that the neutral calcium line increases relative to the ionized calcium lines.

The fact that the lines of *Ca* II, *Mg* I, and *O* I decrease in intensity and the *Ca* I line remains roughly constant when all would be expected to become stronger with the decreasing excitation conditions in the various shells probably means that the shells of lower excitation contain less matter.

TABLE 4

ABSORPTION-LINE INTENSITIES IN SHELL SPECTRA*

Name	*Fe* III	*Fe* II	*Fe* I	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
γ Cassiopeiae	+++	.....	.....	12	....	1	....	2b1	3	1	....	....	B0e
ζ Tauri	+	+++	.....	3	4	3	4	4	7	6	0	4	B3e
ϵ Capricorni	?	+++	.....	1	3	0?	2	2	8	6	3	4	B3e
β Monocerotis	.....	+++	.....	0	2	....	.....	.....	3	2	1	2	B2e
Pleione	.....	+++	+	0?	1	0?	2	2	3	2	3	4	B8e
HR 8731	.....	+++	++	0??	2	0?	2	1	6	4	2	3	B3e
ψ Persei	.....	++	+	.....	0	....	.....	.....	4	3	2	3	B5e

* Struve did not find *Ca* I 4226 present at the time of his study.

If the state of excitation shown by the shell is high, the chances are that the photospheric spectral class is an early B. As the shell excitation conditions decrease from star to star, the photospheric spectral type becomes later. The progression is not uniform, but the difficulty of classifying a stellar spectrum through the blurring haze of a shell is well known and may account for the discrepancies.

If a general rule may be formulated from so small a number of examples, it would be that the cooler the photosphere of a rotating B star, the less material can be supported in a shell and the lower is the state of excitation exhibited by the shell spectrum.

The plates used in this investigation were all taken at the Observatory of the University of Michigan and were loaned to the author through the kindness of Dr. Dean B. McLaughlin and the late Dr. Heber D. Curtis.

FIVE SPECTROSCOPIC BINARIES*

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Received January 18, 1943

ABSTRACT

SX Aurigae.—Spectroscopic observations yield $K_1=172$, $K_2=322$ km/sec, and the photographic luminosity ratio of the two components, $l_2/l_1=0.45$. These results are combined with Oosterhoff's accurate light-curve to obtain values of the masses, radii, and luminosities and estimates of their uncertainties.

V Puppis.—We find $K_1=199$, $K_2=342$ km/sec, and $l_2/l_1=0.57$. The value of K_1+K_2 is significantly smaller than that obtained by Miss Maury. New values of the masses, radii, and luminosities of the components are adopted, though the light-curves of Roberts and van Gent are in poor agreement.

ζ Centauri.—Here also K_1(111 km/sec)$+K_2$(159 km/sec) is smaller than Miss Maury's older determination. An improved value of the period is obtained.

RV Scuti.—With the exceptions of λ 4026 and λ 4088, all strong lines show stationary displacements and originate in a shell. If the variations of the positions of these two lines, which are in phase with Gaposchkin's light-elements, represent orbital motion, the mass of the system is well in excess of 100⊙.

i Bootis B.—We find $K_1=115$, $K_2=231$ km/sec, and $l_2/l_1\approx0.6$. A period 15×10^{-7} days longer than that obtained by Plaut from the photometric data is required to satisfy the spectroscopic observations.

SX AURIGAE (BD+41°1101)

1. A good photographic light-curve of SX Aurigae has been obtained by Oosterhoff.[1] The period is 1.210 days, the magnitude at maximum light 8.21 and at the two minima 8.97 and 8.67. Oosterhoff's observations were discussed by Wyse,[2] who also observed the spectrum and found it to be of class B4.

2. Between September, 1939, and April, 1941, 37 spectrograms of SX Aurigae were obtained at the McDonald Observatory with a dispersion of 76 A/mm at $H\gamma$. The last 25 of these were on high-contrast Process film. Though the spectrum lines are very diffuse and the two components differ considerably in strength, they are observable as separate lines during about one-half the period of revolution (see Pl. XXIX). The lines of the brighter component were measured on 22 spectrograms, while those of the fainter were measured on 17. The spectral type, which appears to be nearly the same for the two stars, is estimated as B3.5. No high-luminosity characteristics are present.

The measured separations of the hydrogen lines of the two components were found to correspond to about 25 km/sec less, on the average, than those of the helium lines. Microphotometer tracings confirm that the hydrogen lines are blended because of their strong wings. Hence the measured velocities are derived from the helium lines alone. The average probable error of a velocity, derived from the internal agreement of the lines measured, is ±12 km/sec for the brighter star and ±21 km/sec for the fainter.

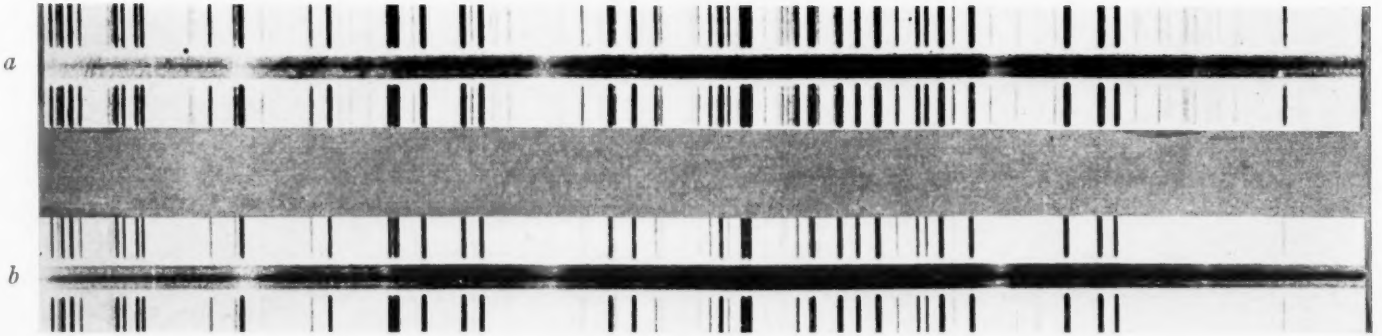
Table 1 lists the observations. Phases were obtained from Oosterhoff's light-elements and are given as fractions of the period measured from primary minimum. V_1 is the measured velocity of the brighter star, and V_2 that of the fainter. The weights for the two stars are not on the same scale. The residuals, O−C, are also listed, where O is the observed value and C the value computed from the adopted elements.

Adopting a result from the photometric observations, we assume the orbit to be circular. The velocity of the center of mass, γ, is determined from the measures of the brighter component only. In computing the amplitude of velocity variation of the fainter

* *Contributions from the McDonald Observatory, University of Texas*, No. 68.

[1] *B.A.N.*, **7**, 107, 1933. [2] *Pub. A.S.P.*, **46**, 126, 1934.

PLATE XXIX



SPECTROGRAMS OF SX AURIGAE

(*a*) JD 2430093.586, 0.262 phase; (*b*) JD 2430073.664, 0.800 phase

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component, K_2, I have assumed this value of γ. The values of the elements obtained from a least-squares solution are

$$K_1 = 172 \pm 4 \text{ (p.e.) km/sec}, \quad K_2 = 322 \pm 7, \quad \gamma = +3 \pm 4.$$

On the basis of the residuals, the probable error of a velocity of weight unity is ± 16 km/sec for V_1 and ± 21 km/sec for V_2. Figure 1 shows the measured velocities and the curve computed from the adopted elements.

Measures of the interstellar K line lead to a velocity of $+7.6 \pm 1.0$ km/sec, while the color index, determined from measures of three panchromatic films,[3] is -0.18 ± 0.03 mag. on the international system.

TABLE 1

OBSERVATIONS OF SX AURIGAE

Julian Day	Helioc. Phase	V_1 (km/sec)	Wt.	O−C	V_2 (km/sec)	Wt.	O−C
2429519.946	0.212	−149	½	+15	+293	¼	− 23
567.807	.767	+135	½	−39	−388	¼	− 71
667.653	.278	−224	¼	−60	.....	.....	.....
670.676	.776	+143	½	−30	−277	½	+ 38
679.594	.146	−158	½	−24	.....	.....	.....
681.585	.790	+156	½	−14	.....	.....	.....
684.637	.312	−151	¼	+ 5	+188	¼	−113
888.951	.155	−139	1	0	+300	1	+ 31
922.917	.227	−189	½	−22	.....	.....	.....
925.948	.732	+164	1	−10	−345	1	− 28
944.758	.278	−166	1	0	+275	1	− 45
950.887	.343	−164	1	−24	+311	½	+ 40
952.738	.872	+118	1	− 9	−257	½	− 28
971.799	.625	+187	1	+62	.....	.....	.....
990.731	.269	−199	1	−31	+303	½	− 20
995.634	.321	−114	1	+38	+301	1	+ 8
2430028.867	.784	+168	1	− 3	−343	1	− 31
041.672	.365	−124	1	+ 2	+291	½	+ 46
062.759	.789	+179	1	+ 9	−254	½	+ 55
073.664	.800	+168	1	+ 1	−279	½	+ 24
093.586	.262	−133	1	+36	+338	1	+ 14
096.592	0.746	+174	1	− 1	−299	1	+ 20

Microphotometer tracings were measured to determine the relative luminosities of the two stars. The methods developed by Petrie[4] were employed. Four spectrograms of the double-lined phase and three of the single-lined phase were used. Calibration was afforded by a tube sensitometer. The lines $H\delta$, $H\gamma$, *He* I 4026, and *He* I 4471 were measured. On the assumption of equal spectral types, I find the following values for the luminosity ratio in the photographic region of the spectrum:

Line	l_2/l_1	Line	l_2/l_1
$H\delta$	0.38	4471	0.46
$H\gamma$	.45	Mean	0.45
4026	0.52		

The approximate equality of the values from lines of *H* and *He* is an objective confirmation of the estimated equality of the spectral types, since, in the spectral range in-

[3] For the method used see Seyfert and Popper, *Ap. J.*, **93**, 463, 1941.

[4] *Pub. Dom. Ap. Obs., Victoria*, **7**, 205, 1939. The effects of instrumental profile are eliminated by measures of the lines at both single and double phases.

volved, *H* lines are strengthening and *He* lines are weakening with advancing spectral type. The brighter star is eclipsed at zero phase, in agreement with the result derived from the light-curve.

3. We are now in a position to combine spectroscopic and photometric data in order to obtain values of the masses, radii, and luminosities of the stars.

The observed ratio of the surface brightnesses of the stars, calculated from the depths of the minima of the light-curve after rectification, is $J_1/J_2=1.60$. It is difficult to understand how two stars of apparently the same spectral type can differ so greatly in surface

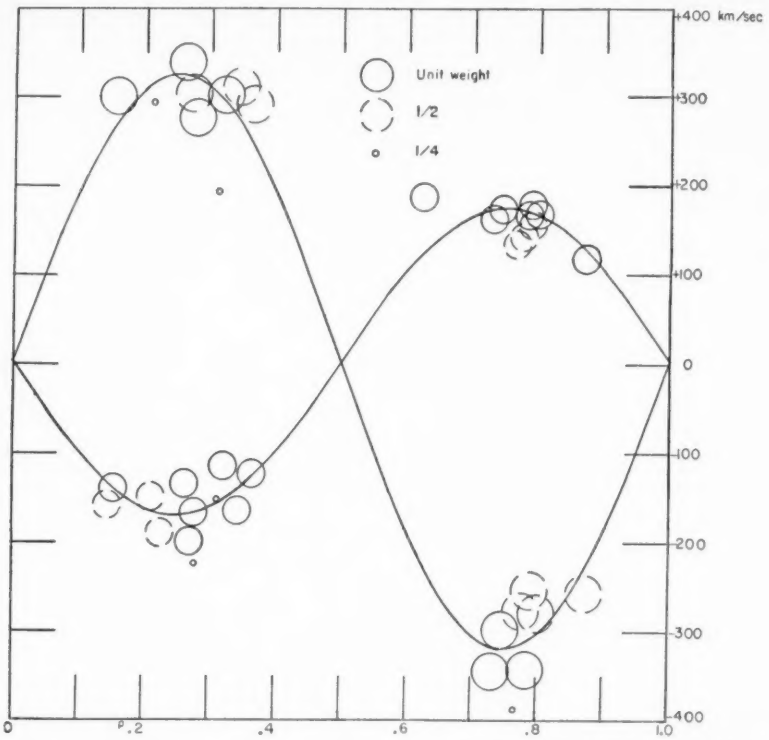


FIG. 1.—Spectroscopic orbit of SX Aurigae. The radii of the circles are equal to the probable errors of observations of unit weight.

brightness. The fainter star should have relatively much weaker helium lines than the brighter. A consideration of the reflection effect, which Wyse found to be present in the case of SX Aurigae, does not improve the situation. The ratio $J_1/J_2=1.60$ refers presumably to the brighter hemispheres of the two stars. The hemispheres facing us when the spectrum lines are seen separated will, if anything, have a slightly larger ratio of surface brightnesses, and the spectra should appear to differ slightly more than the ratio J_1/J_2 predicts. This discrepancy introduces larger uncertainties in the discussion of SX Aurigae than any other observational datum. We shall see how all of this uncertainty may be thrown into the computation of the luminosities.

It has been pointed out by Russell,[5] among others, that in the interpretation of light-curves of eclipsing binaries it is advisable to assume that the true shapes of the stars are those obtained from dynamical considerations rather than those given by the photo-

[5] *Ap. J.*, **94**, 159, 1941.

metric "ellipticities." Since we know the mass ratio of the stars and have approximate values of their major axes relative to the orbital radius,[2] we can compute their shapes on the basis of the Roche model. Using the values $m_2/m_1=0.535$, $a_1/r=0.47$, $a_2/r=0.40$, we find

$$a_1/b_1/c_1=1.084/1/0.919, \quad a_2/b_2/c_2=1.180/1/0.908 .$$

Here m_1 and m_2 are the masses of the brighter and fainter star, respectively, and a, b, and c are their semi-axes. It is assumed that the long axes, a, are always in the line of centers and that c_1 and c_2 are the axes of rotation. The distance between centers is given by r. The true shapes of stars as close together as the components of SX Aurigae are not ellipsoids. We shall neglect the effects of such distortions.

The value $l_2/l_1=0.45$ combined with $J_1/J_2=1.60$ leads to a value for the ratio of the radii, $k=0.85$. But this value refers to the stars as seen near elongation:

$$\frac{(a_2c_2)^{1/2}}{(a_1c_1)^{1/2}}=0.85 .$$

The shape of the light-curve during eclipse, however, depends mostly on b_1 and b_2. Using the Roche values for the ratios of the axes, we find $b_2/b_1=0.82$. This is very near the value $k=0.80$, found by Wyse from the shape of the light-curve.

The mean dynamical value of the ellipticity constant,

$$z=\left[1-\left(\frac{b}{a}\right)^2\right]\sin^2 i ,$$

weighted according to the photographic luminosities of the stars is $z=0.187$, where i, the angle of inclination of the orbit plane to the sky plane, is taken to have the value given by Wyse. Wyse found the photometric ellipticity to be $z=0.220$.

With the values $z=0.187$ and $k=0.82$ we find from the rectified light-curve

$$\frac{b_1}{r}=0.426 , \qquad \frac{b_2}{r}=0.349 , \qquad \cos i=0.170 .$$

The mean radii, $R=(abc)^{1/3}$ can now be calculated. The value of $\cos i$ should be reduced by the mean ratio of $c/(b \sin i)$, since, in its determination from the light-curve, c was assumed equal to b. Thus we have finally

$$\frac{R_1}{r}=0.425 , \qquad \frac{R_2}{r}=0.357 , \qquad \cos i=0.157 .$$

Kopal has undertaken an elaborate formulation of the effects of dynamical distortion and of gravity darkening on the light-curves of close eclipsing systems.[6] He concludes that rectification of a light-curve in the customary manner takes care of some of the outstanding terms resulting from his theory, while the most important remaining terms may be approximated by a fairly simple analytical expression in the case of no limb darkening. Although SX Aurigae is not an extreme case of a close system, the components are close enough ($a_1+a_2=0.87r$) to make a calculation of Kopal's terms interesting. Using the elements derived above, I have computed the loss of light to be expected in primary minimum according to Kopal's formulation for no limb darkening. In Table 2 the "observed" curve is the rectified curve given in Wyse's paper. The parameter α is $1/k^2$ times the fraction of the obscured area of the eclipsed star, the value of α at mid-eclipse being 0.862. In the column C_1 are listed the values of Δ mag. computed in the ordinary way from the elements adopted, while C_2 gives the values computed from Kopal's formulae.

[6] *Proc. Amer. Phil. Soc.*, **85**, 399, 1942; *Ap. J.*, **96**, 20, 1942.

The three curves are shown in Figure 2. We see that, except near the middle of the eclipse, the corrections introduced by the advanced theory are small. To ascertain the approximate effect of these corrections on the derived elements, we may correct the C_1 curve by

TABLE 2

OBSERVED AND COMPUTED LOSS OF LIGHT IN PRIMARY MINIMUM

α	Δ MAG.			α	Δ MAG.		
	Observed	C_1	C_2		Observed	C_1	C_2
0.10	0.056	0.052	0.051	0.60	0.348	0.363	0.371
.20	.107	.109	.107	.70	.423	.437	.451
.30	.161	.166	.168	.80	.507	.515	.535
.40	.215	.228	.231	0.862	0.570	0.570	0.591
0.50	0.276	0.292	0.300				

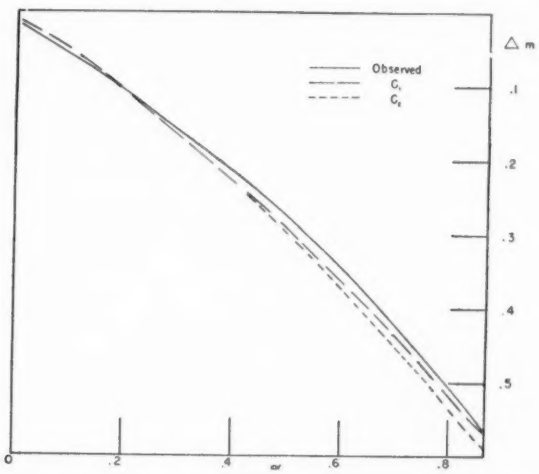


FIG. 2.—Rectified light-curve of SX Aurigae at primary minimum

the amount C_1-C_2 and obtain new values for b_1 and i. They are shown in the accompanying table. The error introduced in using the usual methods of reduction is less than that

	Adopted Values	New Values
b_1/r	0.426	0.414
i	81°.0	80°.6

introduced by the uncertainty in the adopted value of k and probably less than that introduced by the neglect of limb darkening.

With the values $K_1=172$ km/sec, $K_2=322$ km/sec, $i=81°.0$, we find the radius of the relative orbit to be

$$r=12.0\ R\odot\ .$$

Hence

$$R_1 = 5.18\ \mathrm{R}\odot, \quad \log R_1 = 0.714 \pm 0.025\,;$$
$$R_2 = 4.32\ \mathrm{R}\odot, \quad \log R_2 = 0.636 \pm 0.025\,.$$

Kuiper's tabulated corrections for the reflection effect[7] have been applied.

The uncertainty ± 0.025 in $\log R$ is not a probable error and has no statistical significance. It has been estimated as follows: The uncertainty in l_2/l_1 is taken to be 10 per cent, whence that in k is 5 per cent. The light-curve is an accurate one; and, if our procedure is correct, R_1/r and R_2/r should have $\frac{1}{2}\sqrt{2}$ of the uncertainty of k. We shall take $\Delta R/r = 5$ per cent. The uncertainty in K_1 and in K_2 is 2.5 per cent, hence that in r is 3.5 per cent. Then that of $R/R\odot$ is about 6 per cent, and of $\log R$, 0.025.

The masses of the stars, if we take reflection into account, are

$$m_1 = 10.80\odot, \quad \log m_1 = 1.03 \pm 0.03\,;$$
$$m_2 = 5.66\odot, \quad \log m_2 = 0.75 \pm 0.03\,.$$

In this case the uncertainty depends almost entirely on that of the observed K's.

For the bolometric luminosities we have,

$$\frac{L}{L_\odot} = \left(\frac{R}{R_\odot}\right)^2 \cdot \left(\frac{T_e}{T_{e_\odot}}\right)^4;$$

The values of R have been determined. We may take T_e from Kuiper's discussion of the effective temperature scale.[8] But we have seen that the surface brightnesses of our stars differ, whereas their spectral types appear to be the same. In order that our adopted luminosities, L, may be consistent with the observed values of l_2/l_1 and of J_2/J_1, we must have

$$2.5 \log \left(\frac{J_2}{J_1}\right) = (10 \log T_{e_2} + \mathrm{B.C.}_2) - (10 \log T_{e_1} + \mathrm{B.C.}_1)\ ,$$

where the bolometric corrections, B.C., are to be the values associated with the respective values of T_e. Strictly speaking, the bolometric corrections should be to photographic rather than to photovisual magnitudes. The difference is a small one.

We shall adopt the values $\log (T_{e_1}/T_{e_\odot}) = +0.53$, $\log (T_{e_2}/T_{e_\odot}) = +0.42$, $\mathrm{B.C.}_1 = -2.09$, $\mathrm{B.C.}_2 = -1.48$. These values correspond to spectral types B2.5 and B5, respectively. As a measure of our dilemma, I have taken the uncertainty in $\log T_e$ to be ± 0.06. Then we find

$$\log L_1 = 3.55 \pm 0.25, \quad M_{\mathrm{bol}_1} = -4.3 \pm 0.6, \quad M_{\mathrm{pv}_1} = -2.2 \pm 0.6\,;$$
$$\log L_2 = 2.95 \pm 0.25, \quad M_{\mathrm{bol}_2} = -2.8 \pm 0.6, \quad M_{\mathrm{pv}_2} = -1.3 \pm 0.6\,.$$

It is interesting to note that these values of M_{pv} correspond to spectral types B2 and B4 as determined by R. E. Wilson[9] for the main sequence.

This completes our discussion of SX Aurigae. The principal quantities found are

$$\log R_1 = 0.71 \pm 0.02, \quad \log m_1 = 1.03 \pm 0.03, \quad M_{\mathrm{bol}_1} = -4.3 \pm 0.6\,;$$
$$\log R_2 = 0.64 \pm 0.02, \quad \log m_2 = 0.75 \pm 0.03, \quad M_{\mathrm{bol}_2} = -2.8 \pm 0.6\,.$$

[7] *Ap. J.*, **88**, 498, 1938. [8] *Ibid.*, p. 429. [9] *Ap. J.*, **94**, 12, 1941.

It is to be emphasized that the ± quantities are not probable errors but are roughly estimated uncertainties. They depend on the accuracy of the observations and on the compatibility of spectroscopic and photometric data. If the data have not been treated properly, additional inaccuracies are present.

V PUPPIS

1. The spectrum of V Puppis has been described by Miss Maury,[10] who also published a relative spectroscopic orbit.[11] Light-curves were determined by Roberts[12] and by van Gent.[13] The spectral types are given as B1 and B3, the lines of the B3 star being 7/10 as strong as those of the B1 star. The magnitude at maximum light is 4.4 and at the two minima, 4.9 and 5.0. The period is 1.4545 days.

2. This star was observed spectroscopically at the McDonald Observatory between February, 1940, and April, 1941. Thirty spectrograms were obtained on Process film. Of these, 6 have a dispersion of 26 A/mm at $H\gamma$, while the remainder have one-third that dispersion. Double lines were measured on 17 spectrograms, including the 6 of higher dispersion. Miss Maury's estimates of the spectral types and relative line intensities are confirmed, though the difference in spectral type may not be quite so much as 2 subclasses. The spectra appear to be those of main-sequence stars.

As in the case of SX Aurigae, it was found necessary to base the measured velocities on the helium lines alone. The measures are given in Table 3. The respective columns are as in Table 1, except that all velocities are given equal weight. The phases are computed from van Gent's elements. The average probable errors of measurement are ±12 km/sec for the brighter star, and ±13 km/sec for the fainter.

An orbital eccentricity as large as that (0.08) found by Miss Maury is not confirmed by the photometric observations, and it has been neglected in computing the elements. Equal weight was given to the two components in determining the center of mass velocity, γ. From the residuals the probable error of a single velocity is ±16 km/sec for V_1 and ±23 km/sec for V_2. Figure 3 shows the observations, together with the curves predicted by the elements, which are

$$K_1 = 199 \pm 4 \text{ (p.e.) km/sec}, \quad K_2 = 342 \pm 6, \quad \gamma = +20 \pm 3 .$$

The value of $K_1 + K_2$, 541 km/sec, is 11 per cent less than the value found by Miss Maury. This is a serious discrepancy. The six spectrograms of higher dispersion taken alone give $K_1 + K_2 = 551$ km/sec, not significantly different from our adopted value. A test of the correctness of my measures was made from microphotometer tracings of 9 spectrograms which show double lines. The comparison spectrum was recorded simultaneously with that of the star (see Pl. XXX). The separations of the lines on the tracings were converted to kilometers per second, and the differences of the separations—tracing *minus* measure and tracing *minus* orbit—were formed for each spectrogram. The means of the 9 differences are,

$$\text{Tracing} - \text{orbit} = +1 \text{ km/sec}; \quad \text{Tracing} - \text{measure} = -13 \text{ km/sec} .$$

The tracings yield slightly smaller separations than do the measures that were used in computing the elements.

A still further check on the possibility of systematic errors in my measures appears desirable, since the same discrepancy with Miss Maury's results is found in the case of ζ Centauri (see below), whereas Struve[14] found a value of $K_1 + K_2$ for μ^1 Scorpii only 3 per

[10] *Harvard Ann.*, **28**, 177, 1897.

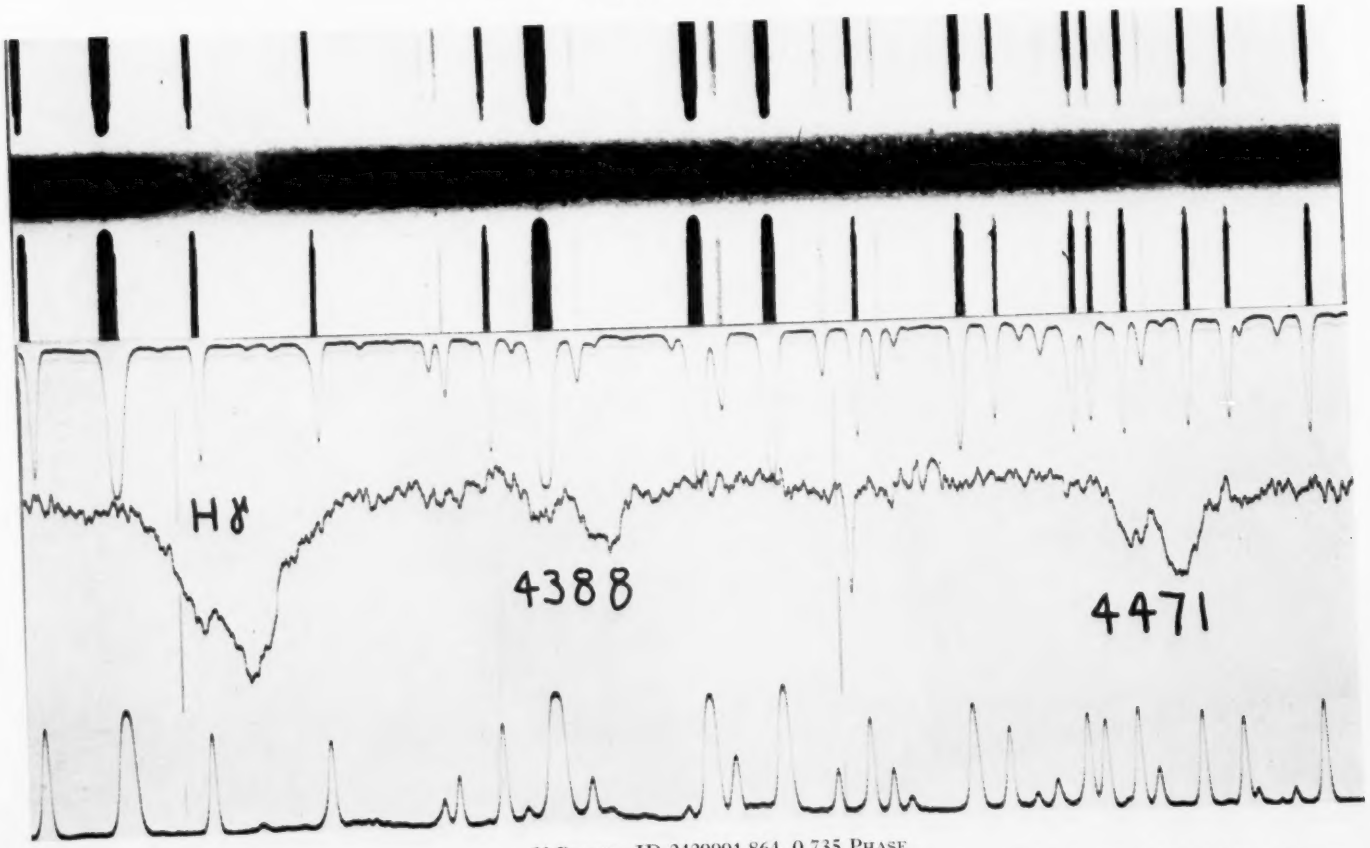
[11] *Ibid.*, **84**, 142, 1920.

[12] *Ap. J.*, **13**, 181, 1901.

[13] *B.A.N.*, **8**, 319, 1942.

[14] *Astronomical Papers Dedicated to E. Strömgren*, p. 258, Copenhagen, 1940.

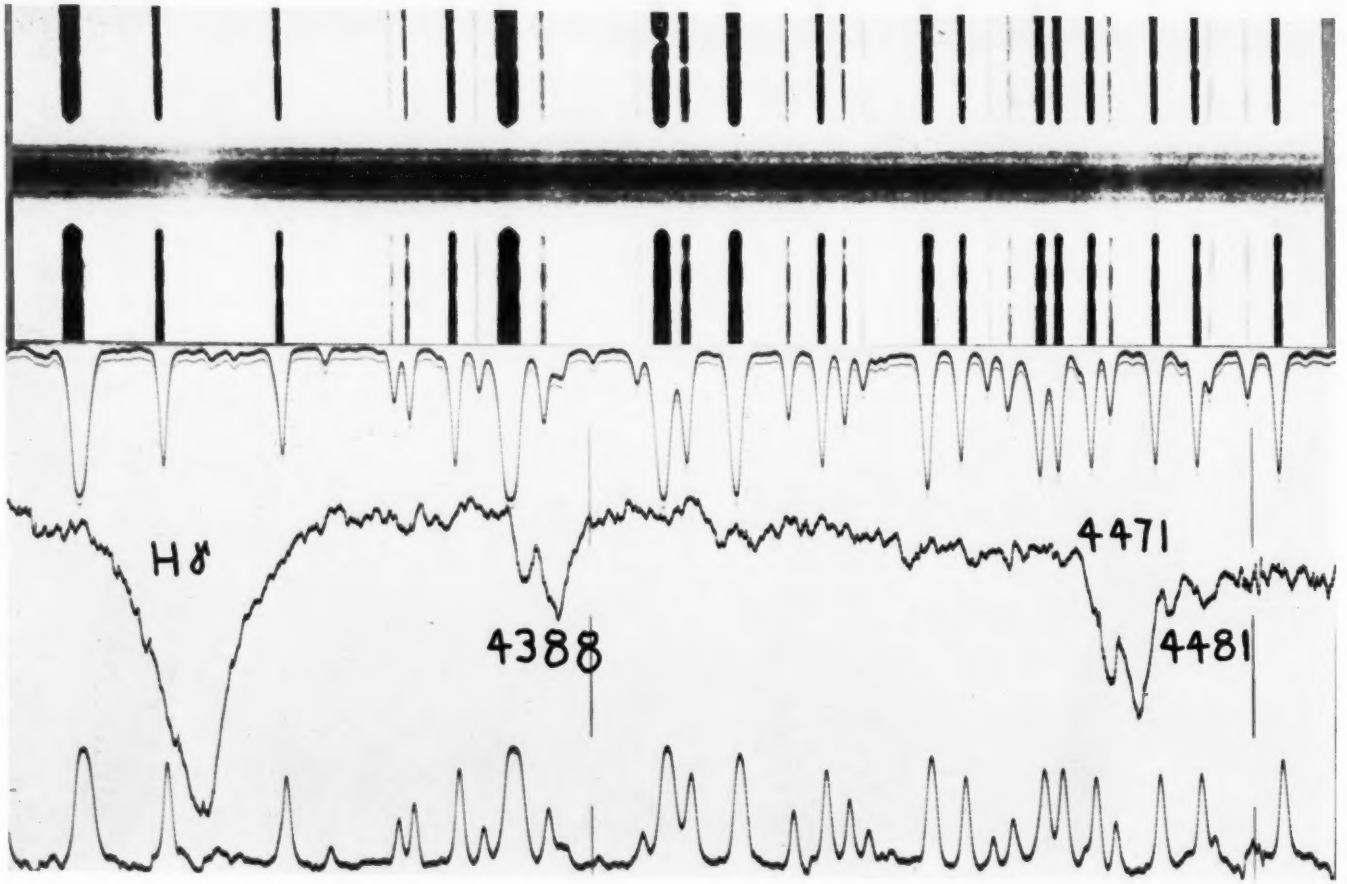
PLATE XXX



V Puppis, JD 2429991.864, 0.735 Phase

Separation of components predicted by our orbit, 541 km/sec; separation of components predicted by Miss Maury's orbit 604 km/sec

PLATE XXXI



ζ Centauri, JD 2430095.77, 0.052 Phase

Separation of components predicted by our orbit, 310 km/sec; separation of components predicted by Miss Maury's orbit, 363 km/sec

TABLE 3

OBSERVATIONS OF V PUPPIS

Julian Day	Helioc. Phase	V_1 (km/sec)	O−C	V_2 (km/sec)	O−C
2429666.764	0P.221	−190	−15	+359	+ 4
677.724	.756	+182	−37	−365	−43
710.629	.378	−133	−14	+192	−67
715.625	.813	+248	+44	−263	+33
733.583	.160	−160	−12	+349	+41
734.585	.849	+211	+29	−204	+55
949.915	.893	+126	−18	−188	+ 5
985.845	.597	+109	−24	−151	+23
986.884*	.311	−153	+10	+346	+ 8
991.840	.719	+223	+ 8	−298	+17
991.864*	.735	+212	− 6	−329	− 9
2430069.678*	.234	−144	+34	+376	+16
093.609	.688	+205	+ 2	−317	−22
093.648*	.714	+216	+ 2	−358	−45
094.599*	.368	−127	+ 1	+272	− 2
101.592*	.176	−182	−25	+332	+ 7
101.623	0.197	−148	+20	+310	−32

* Dispersion 26 A/mm at Hγ.

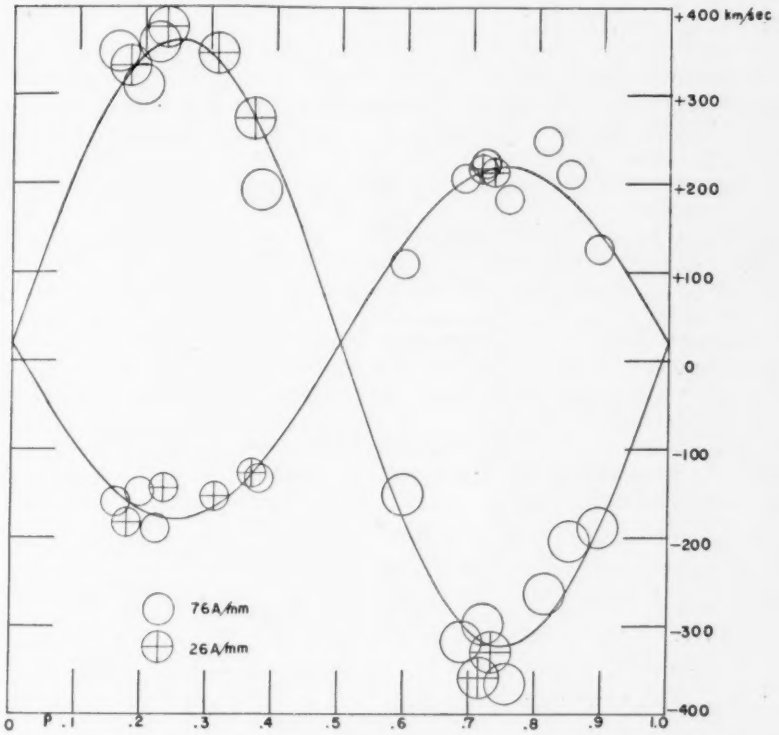


FIG. 3.—Spectroscopic orbit of V Puppis. The radii of the circles are equal to the probable errors of an observation.

cent less than that given by Miss Maury. I have obtained 6 spectrograms of μ^1 Scorpii with the dispersion 26 A/mm,[15] which was also used for the spectrograms of ζ Centauri. From measures of *He* lines only, I find a mean separation of the lines only 10 km/sec (2 per cent) less than predicted from Struve's elements. The evidence from comparison of spectrograms of different dispersions, from the microphotometer tracings, and from spectrograms of μ^1 Scorpii appears to point to no serious systematic errors in my measures.

The interstellar K-line velocity is $+17.7 \pm 2.3$ km/sec. Both this velocity and that of the center of mass of the system are very nearly equal to a reflection of the peculiar motion of the sun.

As in the case of SX Aurigae, intensity measures of the lines were made from microphotometer tracings of the best spectrograms in order to determine the ratio of photographic luminosities of the component stars. The results from spectrograms of the two dispersions are in good agreement. On the assumption of equal intrinsic line intensities for the two stars, we find for the photographic-luminosity ratio the following values:

Line	l_2/l_1	Line	l_2/l_1
$H\delta$	0.67	*He* I 4026	0.73
$H\gamma$	0.66	*He* I 4471	0.69

The mean, 0.69, is identical with the visual estimate made by Miss Maury. As we pass from type B3 to type B1, however, the lines of both *H* and *He* weaken by a factor of about 0.7. Since the two stars are probably a little closer in type than 2 subclasses, we shall take this factor to be 0.8, and hence we have $l_2/l_1 = 0.55$. The photovisual regions, in which the photometric observations were made, will be more nearly equal in strength. We shall adopt $l_2/l_1 = 0.57$.

Our relatively meager material does not confirm the complex structure and the changes in appearance of the lines reported by Miss Maury. Most of the spectrograms are of too low dispersion to reveal such effects. On the low-dispersion spectrograms on high-contrast film the lines of V Puppis appear as reasonably good lines—much sharper, for example, than those of SX Aurigae. Neither visual inspection of the films nor measures of microphotometer tracings shows a systematic variation of line intensities from one node to the other.

3. Roberts' and van Gent's photometric observations are in fair agreement in evaluating the ratio of surface brightness as $J_1/J_2 = 1.32$. This is about the ratio to be expected of stars of the difference of spectral class of the components of V Puppis. Combining the values of J_1/J_2 and l_2/l_1, we find the ratio of the radii, $k = 0.87$.

Neither of the published light-curves is of sufficient accuracy to warrant a lengthy discussion of the values of the radii of the stars, such as was made for SX Aurigae. Moreover, the eclipse portions of the two curves differ by much more than the changes introduced by such refinements. Van Gent's curve has narrower minima and leads to smaller stars than does Roberts'. Using our value of k and the dynamical value for the ellipticity constant (see the discussion for SX Aurigae above), $z = 0.136$, we find from the two curves the values shown in the accompanying table. Then, from the shapes of the Roche ellip-

	van Gent	Roberts	Adopted
b_1/r	0.35	0.44	0.38
i	77°	75°	77°

soids, as in the case of SX Aurigae, we find

$$\frac{R_1}{r} = 0.38 \pm 0.05\,, \qquad \frac{R_2}{r} = 0.33 \pm 0.05\,.$$

[15] These spectrograms cover a different spectral region from those used by Struve.

The estimated uncertainty of R/r arises mostly from the uncertainty of the light-curve, though also in part from an uncertainty in the value of k. The values of the luminosities and radii of V Puppis would be greatly improved if a definitive light-curve were obtained. Neither light-curve gives a good fit of observation and theory throughout the minima.

From the values of K_1, K_2, i, and the period, $1^d.4545$, we find

$$r = 16.0 \pm 0.5\ R\odot\ ,$$

and hence

$$R_1 = 6.1\ R\odot, \quad \log R_1 = 0.79 \pm 0.06\ ;$$
$$R_2 = 5.3\ R\odot, \quad \log R_2 = 0.72 \pm 0.06\ .$$

The masses of the stars, taking reflection into account, we find to be

$$m_1 = 16.5\odot, \quad \log m_1 = 1.22 \pm 0.04\ ;$$
$$m_2 = 9.7\odot, \quad \log m_2 = 0.99 \pm 0.04\ .$$

The uncertainty of 10 per cent in the masses is estimated from an uncertainty in K_1 and K_2 of 2 per cent, and in $\sin^3 i$ of 3 per cent.

In computing the bolometric luminosities, we must have

$$2.5 \log \frac{J_2}{J_1} = (10 \log T_{e_2} + \text{B.C.}_2) - (10 \log T_{e_1} + \text{B.C.}_1)\ .$$

We adopt

$$\frac{\log T_{e_1}}{T_{e_\odot}} = 0.59\ , \qquad \frac{T_{e_2}}{T_{e_\odot}} = 0.52\ , \qquad \text{B.C.}_1 = -2.41\ , \qquad \text{B.C.}_2 = -2.04\ ,$$

corresponding to spectral types B1 and B3$^-$, respectively. Then we obtain

$$\log L_1 = 3.94 \pm 0.14, \quad M_{\text{bol}_1} = -5.2 \pm 0.4, \quad M_{\text{pv}_1} = -2.8 \pm 0.4\ ;$$
$$\log L_2 = 3.52 \pm 0.14, \quad M_{\text{bol}_2} = -4.2 \pm 0.4, \quad M_{\text{pv}_2} = -2.1 \pm 0.4\ .$$

The estimated uncertainties in $\log L$ arise from the uncertainty 0.06 in $\log R$ and 0.02 in $\log T_e$.

Bringing together the important quantities found for V Puppis, we have

$$\log R_1 = 0.79 \pm 0.06, \quad \log m_1 = 1.22 \pm 0.04, \quad M_{\text{bol}_1} = -5.2 \pm 0.4\ ;$$
$$\log R_2 = 0.72 \pm 0.06, \quad \log m_2 = 0.99 \pm 0.04, \quad M_{\text{bol}_2} = -4.2 \pm 0.4\ .$$

These values are all somewhat smaller than those used by Kuiper for the mean component in his compilation for a study of the mass-luminosity relation.[16] The similarity between the brighter component of SX Aurigae and the fainter component of V Puppis is striking.

ζ CENTAURI

Mrs. Fleming in 1898 found ζ Centauri to be a spectroscopic binary with double lines. Miss Maury has published the relative orbit as determined from objective-prism spectrograms.[17] The star was placed on our observing program in order to obtain the mass ratio.

[16] *Op. cit.*, p. 472.

[17] *Harvard Circ.*, No. 233, 1922.

Table 4 lists those McDonald observations which show double lines. The spectrograms have a dispersion of 26 A/mm at $H\gamma$. Only the helium lines could be used in the measures of radial velocity. The average probable error of measurement is ± 5 km/sec for each component. The measures of the two components are given equal weight. The phases are fractions of a period measured from periastron passage calculated from the elements adopted below.

TABLE 4

OBSERVATIONS OF ζ CENTAURI

Julian Day	Phase	Wt.	V_1 (km/sec)	O−C	V_2 (km/sec)	O−C
2429798.61.....	0P018	½	+ 92	− 7	−113	+14
799.60.....	.142	1	+112	+ 2	−152	−10
820.60.....	.759	¼	− 54	+19	+110	− 9
831.60.....	.130	1	+118	+ 2	−156	− 5
836.60.....	.753	¼	− 63	+ 8	+134	+16
2430069.92.....	.830	1	− 89	− 5	+130	− 6
077.90.....	.825	1	− 87	− 4	+133	− 2
088.88.....	.193	½	+ 97	+10	− 97	+11
095.77.....	.052	1	+127	− 7	−176	+ 1
096.78.....	.128	½	+111	− 6	−122	+30
101.87.....	.812	1	− 65	+17	+132	− 1
182.61.....	.875	½	− 88	− 3	+118	−20
359.05.....	.864	¼	− 51	+35	+117	−21
433.89.....	.191	½	+110	+23	−101	+ 9
440.92.....	.067	1	+149	+13	−191	−11
473.81.....	.166	1	+ 91	− 8	−131	− 4
480.79.....	.036	1	+128	+ 4	−165	− 3
481.75.....	0.155	1	+104	0	−149	−15

With Miss Maury's values of e, ω, and P, which are 0.5, 290°, and 8d024, respectively, and with an epoch determined from inspection of the velocity-curve (see Fig. 4), we may solve for K_1, K_2, and γ. Two-thirds of the weight of the solution lies in the velocities near periastron, since the component lines are not well separated near apastron. The elements are

$$\gamma = +6.5 \pm 1.2 \text{ km/sec}, \qquad m_1 \sin^3 i = 6.4 \odot ,$$
$$K_1 = 110.7 \pm 1.9, \qquad m_2 \sin^3 i = 4.4 \odot ,$$
$$K_2 = 159.4 \pm 2.0, \qquad r \sin i = 37.4 \odot ,$$
$$T = \text{JD } 2429798.46,$$

in which T is the time of periastron passage, m_1 and m_2 are the masses of the stars, and r is the distance between their centers. It is evident from Figure 4 that no substantial improvement of the values of e, ω, and T would be obtained from a differential correction based on so few observations.

The probable errors of the elements have not their usual significance, since the values of e, γ, and T were assumed to be correct. The probable error of a velocity of weight unity in the solution is ± 6.5 km/sec. A comparison of Miss Maury's value of T with ours yields an improved value of the period, $P = 8^d02352$.

The value of $K_1 + K_2$ obtained here is 13 per cent smaller than the value obtained by Miss Maury. A discussion of this discrepancy is found in the preceding section on V Puppis. The discrepancy for ζ Centauri would be reduced to 10 per cent if the measures near apastron were disregarded. As in the case of V Puppis, the line separations were

checked on microphotometer tracings of a number of spectrograms, with similar results (see Pl. XXXI).

Since the lines are not well separated when the fainter star is receding, it is difficult to confirm from the present material Miss Maury's observation that the relative intensities vary systematically with phase, though visual inspection reveals no obvious relationship. Measures of microphotometer tracings of 6 spectrograms are not conclusive on this point. Because of the comparatively small separation of the component lines, the measured relative intensities are subject to considerable scatter. The mean values for each of five helium lines and two hydrogen lines are in good agreement, the intensity ratio being 0.71. Because of the difference in spectral types, we may adopt the value $l_f/l_b=0.65$ in the photographic region of the spectrum.

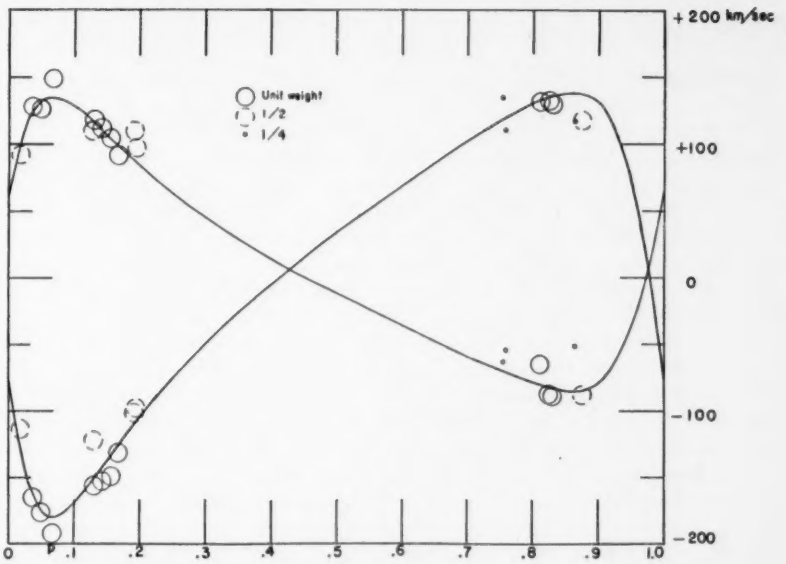


FIG. 4.—Spectroscopic orbit of ζ Centauri. The radius of the circles is equal to the probable error of an observation of unit weight.

The spectral types of the components are B2 or slightly earlier for the brighter and more massive star and B3 or slightly earlier for the fainter, in good agreement with Miss Maury's estimates.

If ζ Centauri is a member of the Scorpio-Centaurus cluster and has a parallax of 0".0074, the absolute magnitudes of the components are

$$M_{v_1}=-2.1, \quad M_{i_2}=-1.6,$$

since the visual magnitude is 3.1. The proper motion of ζ Centauri is 0".076 toward the solar antapex, the τ component being nearly zero. The assumption that this motion is entirely a reflection of the solar motion leads to a parallax of 0".018 and absolute magnitudes of -0.2 and $+0.3$. These latter values seem rather faint for stars of the spectral types of the components of ζ Centauri.

If the sum of the radii of the two stars equals $10\odot$, a probable value, the orbital inclination would have to be greater than 80° for two eclipses to occur and greater than 67° for one eclipse to occur.

RY SCUTI (BD−12°5045)

In their discussion of the peculiar spectrum of RY Scuti, Swings and Struve[18] pointed out that their measures of radial velocity of the absorption and emission components of *He* I 4471 showed no variation. This result confirmed that of Merrill,[19] which was based on measures of emission lines. Gaposchkin,[20] on the other hand, found RY Scuti to be an eclipsing variable of β Lyrae type with two well-defined minima and a period of 11.1 days. Its photographic magnitude varies in the vicinity of 10^m0. Gaposchkin emphasized the possibility that this star may resemble β Lyrae.

Twenty-five spectrograms of RY Scuti have been obtained with a dispersion of 76 A/mm at $H\gamma$. They are well distributed throughout the period of light-variation and cover the photographic region of the spectrum. A definitive discussion of the radial velocities and intensities of the lines will require spectrograms of higher dispersion. It appears desirable, nevertheless, to give a tentative report on the nature of the radial velocities.

All features of the spectrum that were sufficiently well defined were measured for radial velocity. The strongest lines of the photographic region of the spectrum may be classified in three groups: (1) emission lines of [*Fe* III] and *He* II (λ 4686); (2) lines of P Cygni type, namely, *He* I 4471 and the *H* lines; (3) pure absorption lines, the strongest of these being *He* I 4026 and *Si* IV 4088. The emission lines of groups 1 and 2 show a mean displacement of +35 km/sec, in agreement with the results of Merrill and of Swings and Struve. The scatter is large, but the lines are not very sharp. The absorption lines of group 2 show an approximately constant displacement of −145 km/sec, also in agreement with Swings and Struve's measures. On a number of spectrograms absorption lines appear on the long-wave-length side of the P Cygni type emission lines with a displacement of +180 km/sec. In the case of $H\delta$ the line may be *N* III 4101. But for *He* I 4471, $H\gamma$ and $H\epsilon$ the presence of a redward component appears probable. The possibility exists that this component is due to the redward wing of a rotationally broadened underlying line. Such a line would then contribute part of the intensity of the "P Cygni" absorption. In contrast to the lines of groups 1 and 2, λ 4088 behaves as is expected of the lines of the hotter component of an eclipsing binary that has a period and epoch as given by Gaposchkin for RY Scuti. The velocity variation is from −260 to +240 km/sec. For half the period of revolution *He* I 4026 has displacements in approximate agreement with those of λ 4088. When λ 4088 has a positive displacement, however, λ 4026 becomes double. The slightly stronger component has a negative displacement in agreement with the P Cygni type absorption lines, while the second component varies in a manner similar to λ 4088. The better measures of these two lines are shown in Figure 5.

There appears to be little doubt that most of the prominent features of the spectrum of RY Scuti arise in a shell or ring surrounding the binary system. In this sense they resemble the so-called B5 spectrum of β Lyrae.[21] The line λ 4088 and the variable part of λ 4026 appear to be nonshell lines. The material is not adequate for a discussion of the origin of the weaker absorption lines. If the apparent velocity variations of λ 4026 and λ 4088 arise from true orbital motion, the total mass of the system is well in excess of 100 solar masses.

The difference in the behavior of the two lines, λ 4026 and λ 4471, of the diffuse triplet series of *He* I is remarkable. The emission component of λ 4471 masks the stellar line when the latter reaches positive displacements. At negative displacements the ratio of shell- to star-absorption intensity appears to be greater for λ 4471 than for λ 4026. It will be recalled that Struve noted an unusually high gradient for the *He* I lines in the B5 spectrum of β Lyrae.

[18] *Ap. J.*, **91**, 581, 1940.

[19] *Ap. J.*, **67**, 179, 1928.

[20] *Harvard Ann.*, **105**, 511, 1937.

[21] O. Struve, *Observatory*, **57**, 265, 1934.

As noted by Swings and Struve, there are large variations in the intensities of the absorption and emission lines, with the exception of the emission lines of group 1. It has not been possible to correlate these changes with phase.

i BOOTIS B

1. With the possible exception of S Antilae, i Bootis B is the brightest of the known W Ursae Majoris type stars. Moreover, the visual orbit of the system i Bootis AB is fairly well determined.[22] The separation of the components A and B in 1940 was about 2".5 and is decreasing. It will not reach that value again until about 2045 according to Strand's orbit, though in 1996 the distance will be 2".1. The two stars have been well separated at the Cassegrain focus of the 82-inch reflector in good seeing. Since the position angle was near 250°, the slit of the spectrograph was oriented along a right-ascension circle when obtaining spectrograms, and the star was trailed by means of the declination drive.

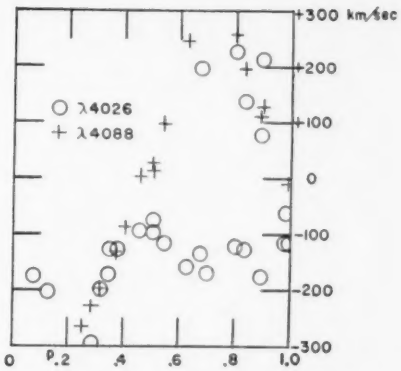


FIG. 5.—Measures of the displacements of λ 4026 and λ 4088 in the spectrum of RY Scuti

Spectrograms were obtained in the photographic region of the spectrum with a dispersion of 26 A/mm at $H\gamma$ in 1940, 1941, and 1942. The observations of 1940 and 1941 each cover a complete revolution of i Bootis B, while those of 1942 cover half a revolution. The average exposure time was 14 minutes in 1940, 8 in 1941, and 5 in 1942, the decrease resulting from the increase in speed of Eastman spectroscopic plates. Since the lines of A are sharp while those of B are diffuse, there is no danger that light from A, which is photographically about 1 mag. brighter than B, will enter the slit undetected. Those observations showing double lines are listed in Table 5. The calculation of the phases is discussed below. The measures of the 2 components have equal weight.

The rotationally broadened lines of this G-type star are all very badly blended. In order to establish a system of wave lengths for radial-velocity determination, the lines of best appearance were measured on 12 spectrograms taken at singe phase. The mean position of each line, corrected for the orbital motion of the earth, was taken to correspond to zero velocity. Only those lines could be used which did not blend still further when shifted to the red or violet by the amounts of the orbital velocities. An average of eight lines per spectrogram was measured for each component. The probable error of a measured velocity is ±6 km/sec.

2. Plaut[23] has discussed the available photometric observations of i Bootis. Because of uncertainties of the magnitude differences between A and B, no solution of the photo-

[22] K. Strand, *Leiden Ann.*, **18**, Part II, 1937.

[23] *B.A.N.*, **9**, 1, 1939.

metric orbit was attempted. Plaut showed that the period is decreasing at present because of the change of light-time due to the orbital motion of B about the center of mass of the system AB. If we adopt a mass ratio $m_A/(m_A+m_B)=0.4^{22}$, a positive value of the orbital inclination as found by Plaut, and use Strand's values for the separation of the

TABLE 5

OBSERVATIONS OF i BOOTIS B

Julian Day	Helioc. Phase	Wt.	V_1 (km/sec)	O−C	V_2 (km/sec)	O−C
2429797.632	0d645	1	−113	−25	+174	−13
.650	.713	1	−127	−18	+226	− 2
.659	.746	1	−124	−12	+224	−10
.668	.780	1	−116	− 6	+228	− 2
.688	.855	1	− 93	− 5	+191	+ 5
.699	.896	½	− 40	+27	+117	−27
.757	.112	½	+ 96	+18	−103	+43
.773	.172	1	+112	+ 7	−207	− 7
2429806.620	.207	1	+129	+14	−238	−19
.629	.240	1	+115	− 4	−231	− 4
.639	.278	1	+138	+21	−233	− 9
.654	.334	1	+118	+13	−203	− 8
.664	.371	1	+100	+13	−176	−12
2430152.608	.126	1	+ 73	−12	−162	− 2
.616	.156	1	+ 95	− 4	−224	−36
.624	.186	1	+ 93	−16	−212	− 3
.631	.212	1	+116	+ 1	−218	+ 3
.639	.242	1	+106	−13	−225	+ 2
.646	.268	1	+143	+25	−237	−11
.654	.298	1	+113	− 1	−224	− 6
.661	.324	1	+106	− 1	−213	− 9
.669	.354	1	+ 95	0	−189	− 8
.737	.608	½	− 63	+ 8	+138	− 9
.744	.634	1	− 90	− 8	+160	−15
.753	.667	1	− 91	+ 6	+184	−20
.760	.693	1	−106	− 1	+224	+ 4
.769	.727	1	−115	− 4	+239	+ 7
.776	.753	1	−103	+ 9	+239	+ 5
.786	.790	1	− 92	+16	+211	−16
.794	.820	1	− 88	+13	+234	+22
2430475.712	.600	½	− 45	+19	+111	−27
.720	.629	1	− 72	+ 8	+128	−43
.728	.659	1	− 77	+18	+192	− 6
.738	.697	1	− 91	+14	+222	+ 1
.750	.741	1	− 98	+14	+238	+ 4
.758	.771	1	−108	+ 3	+213	−19
.767	.805	1	−101	+ 4	+219	− 2
.775	.835	1	− 85	+11	+195	− 8
.783	.865	1	− 76	+ 8	+173	− 5
.792	0.898	½	− 63	+ 3	+117	−24

components projected onto the line of sight, we find that the average apparent period between Plaut's epoch in 1937 and our time of observation should be 3×10^{-7} days shorter than the true period referred to the center of mass of the system. Since the true period found by Plaut is 0d2678082, we should use a period of 0d2768079 to determine the phases of our observations when Plaut's epoch is used as zero point.

Figure 6 shows our velocities plotted against phase determined as described above. The curves represent circular motion. It is evident that the phases should be decreased, i.e., the epoch of our observations is later than the computed epoch. It appears, further,

that the change in epoch increases with the time for our three sets of observations. These circumstances suggest that the period should be increased. We find that a period of $0^d.2678094$ between 1937 and 1942 fits our three sets of observations (see Fig. 7). The probable error of Plaut's evaluation of the period is only 4×10^{-7} days; the discrepancy of 15×10^{-7} days is difficult to explain. A possible explanation might lie in systematic effects caused by blending of the lines. Against this it may be argued that the discrepancy increases with the time, that it appears in the *separations* of the component lines in both halves of the velocity-curve, and that a reasonably large number of lines was measured. The phases given in Table 5 and used in the solution are those obtained with the larger value for the period.

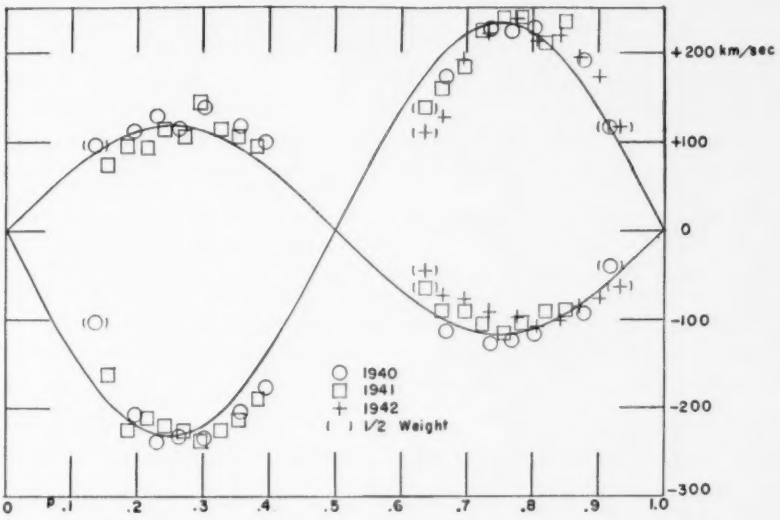


FIG. 6.—Radial velocities of i Bootis B. The phases are determined with the period $0^d.2678079$ and Plaut's epoch.

3. Since the orbit of i Bootis B is approximately circular, we may adopt preliminary values of γ, K_1, and K_2 and may then obtain differential corrections to these elements, as well as values of $e\sin\omega$, $e\cos\omega$, and ΔT_0,[24] where T_0 is the epoch at which $\omega+M=0$. For a circular orbit T_0 is the date of nodal passage. From each spectrogram we obtain two equations of condition:

$$\Delta V_1=\Delta\gamma+f\Delta K_1+K_1\Delta f\,, \tag{1}$$

$$\Delta V_2=\Delta\gamma-f\Delta K_2-K_2\Delta f\,, \tag{2}$$

where f is a function of the elliptical elements and of the time. The ΔV's are the velocity residuals from the preliminary orbit, and the other Δ's are the corrections to the elements. There are several ways in which one may solve for the differential corrections. If we examine the references in Moore's *Fourth Catalogue of Spectroscopic Binary Stars*,[25] we find that in most of the cases where the measures of both components have been used to obtain values of e, ω, and T, a highly questionable procedure has been employed. In effect, equations (1) and (2) have been added,[26] so that the differential corrections depend on

[24] T. E. Sterne, *Proc. Nat. Acad. Sci.*, **27**, 175, 1941.

[25] *Lick Obs. Bull.*, **18**, 1, 1936.

[26] Suggested by W. F. King and referred to in *Pub. Dom. Obs. Ottawa*, **1**, 327, 1914. In our discussion equal weights are implied for the two components. These remarks are not altered significantly if unequal weights are used.

the mean velocity of the two components on each spectrogram. This procedure appears to the writer to have little significance for the problem at hand.

Of the methods that may be used for obtaining differential corrections when both components are used, we may mention three: (*a*) The normal equations obtained from equations (1) and (2) are solved separately. The results for γ and the elliptical elements are then combined to give appropriately weighted means. (*b*) The value of γ is obtained first by a method such as that proposed by O. C. Wilson.[27] The normal equations obtained from equation (1) are solved for ΔK_1 and Δf, and those obtained from equation (2) for ΔK_2 and Δf, and the results are combined for the elliptical elements. (*c*) The values of γ and $K_2/K_1=r$ are obtained first.[27] Then the equation

$$\Delta V_1-\Delta V_2=f(1+r)\cdot\Delta K_1+K_1(1+r)\cdot\Delta f$$

is formed and the normal equations solved for ΔK_1 and Δf. With modifications, this is the method proposed by Paddock[28] and is equivalent to that employed with objective-prism observations. In the latter case γ and K_2/K_1 must remain unknown, V_1-V_2 is the relative velocity, and $K_1(1+r)$ is replaced by the semi-amplitude of the relative velocity-curve.

Which method is used would appear to be largely a matter of personal taste and experience. For the orbit of i Bootis B, where the eccentricity is small, I have used method (*b*). If the eccentricity is significant, $e\cos\omega$ and $e\sin\omega$ should appear independently in the two sets of measures. Proceeding in this manner, we first obtain $\gamma=+3.4\pm1.1$ km/sec. This value has no particular significance, except to indicate the extent to which our adopted mean wave lengths of the blended lines depart from the true ones. Then from the measures of the two components we find:

Brighter Component	Fainter Component
$K_1=115.6\pm1.4$ km/sec,	$K_2=231.7\pm1.7$ km/sec ,
$e\cos\omega=-0.031\pm0.018$,	$e\cos\omega=-0.025\pm0.011$,
$e\sin\omega=-0.044\pm0.018$,	$e\sin\omega=+0.005\pm0.011$,
$\Delta T_0=+0.00012\pm0.00012$ days;	$\Delta T_0=+0.00017\pm0.00007$ days .

Thus we see that the value of $e\sin\omega$ is not well determined, whereas the value of $e\cos\omega$, though in good agreement for the two components, is considerably larger than that admitted by the photometric data,[23] and we may conclude that circular elements are probably the best to adopt. In passing, it is of interest to note the values of the elliptical elements obtained from summing the ΔV's:[26]

$$e\cos\omega=+0.055\pm0.043,\qquad e\sin\omega=+0.051\pm0.024,\qquad \Delta T_0=+0.0021\pm0.0016\text{ days}.$$

If we assume $e=0$, we obtain for the most likely values of the elements

$K_1=115.4\pm1.6$ km/sec,	$K_2=231.1\pm1.9$ km/sec ,
$\Delta T_0=+0.00018\pm0.00007$ days;	$\Delta T_0=+0.00005\pm0.00012$ days .

The residuals in Table 5 and the curves of Figure 7 are obtained from these elements, with $\gamma=+3.4$ km/sec. The value of ΔT_0 is less than the accuracy with which the times

[27] *Ap. J.*, **93**, 29, 1941.

[28] *Lick Obs. Bull.*, **8**, 156, 1915.

of the observations are known. Hence we may conclude that phases computed from Plaut's epoch with the value of the period, $0^d.2678094$, as found above, need no correction. The minimum values of the masses found from these elements are

$$m_1 \sin^3 i = 0.77\odot, \qquad m_2 \sin^3 i = 0.39\odot.$$

Because of the reflection effect in such close systems, the centers of light of the stars are closer together than the centers of mass, so that the values of $m \sin^3 i$ obtained here are too small by an unknown amount.

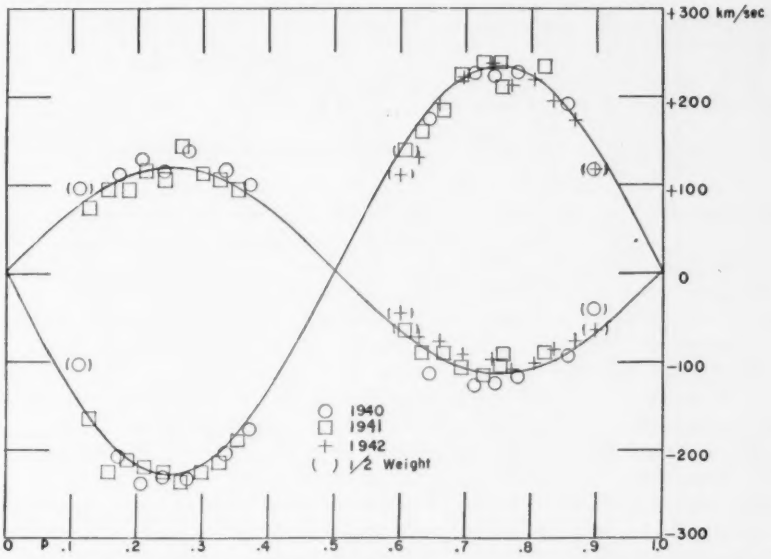


FIG. 7.—Spectroscopic orbit of i Bootis B. The phases are determined with the period $0^d.2678094$ and Plaut's epoch.

4. The luminosity ratio of the components is very difficult to obtain from the spectrograms because of the severe blending of the lines. From a visual inspection I have adopted a ratio of 0.6. One expects a much greater luminosity difference for stars with a mass ratio of $\frac{1}{2}$ in the lower part of the mass-luminosity diagram.[29] The luminosity ratio shown by the spectrograms certainly lies between the values 0.5 and 0.85. There is also considerable uncertainty as to the magnitude of this star.[23] The trigonometric parallax of i Bootis is $0''.079 \pm 0''.007$. If we adopt $m_v = 6.3$ for the magnitude of B outside of eclipse, we find for the components of B

$$M_{v_1} = 6.3, \qquad M_{v_2} = 6.9.$$

[29] *Cf.* Kuiper, *op. cit.*, p. 472.

THE SPECTRA OF U GEMINORUM TYPE VARIABLE STARS*

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ABSTRACT

Spectrograms of several U Geminorum variable stars and of a few related objects have been obtained with the Cassegrain spectrographs on the 82-inch telescope. The linear dispersions varied from 75 A/mm to 340 A/mm at $H\gamma$. Descriptions of the spectra of the following objects are given for one or more phases in their light-curves: UU Aql, SS Aur, SS Cyg, U Gem, X Leo, AY Lyr, RU Peg, SU UMa, TW Vir, RX And, Z Cam, AH Her, CN Ori, TZ Per, EY Cyg, CY Lyr, CO Ori, UX Ori, CL Sco, T Pyx, and V Sge.

A brief summary is given of the characteristics of the spectra of the U Geminorum type of variable stars at minimum and maximum light.

The variable stars of the U Geminorum type form a very interesting group, probably because we know so little concerning the physical processes to which these objects are subjected. Since the discovery of SS Cygni by Miss L. D. Wells[1] in 1896, this star, as well as a number of the other brighter ones of the same class, has been kept under observation by the amateur astronomers. Until the beginning of the present war, not a single maximum of SS Cygni has been missed. Leon Campbell,[2] recorder for the American Association of Variable Star Observers, reports that during the years 1915–1934 SS Cygni was observed on 93 per cent of all the available nights; thus its light-curve is nearly complete. All the other stars of this class are fainter, and, consequently, portions of the light-curves of many of them are missed, since the stars are beyond the limit of the telescopic equipment of many variable-star observers.

The general characteristic of the light-curves of stars of this class is a sudden increase in brightness and a slower decline, suggesting a "flare up" or an explosion; hence they have been classed with the "explosive" variables, such as novae and supernovae. However, the explosions are small in comparison, since the supernovae increase in brightness a hundred million times in a few days and the ordinary novae a hundred and fifty thousand times, while these objects increase in brightness only from ten to one hundred times. The supernovae and most of the ordinary novae have never been observed to erupt a second time, excepting three novae with small ranges in brightness which have been observed to erupt after intervals of several years and have been termed "recurring novae." The stars of the U Geminorum type, the so-called "dwarf novae," erupt at frequent intervals; the average periods between maxima vary from around fifteen days for the shorter ones to nearly a year for those of longer periods.

On the basis of their light-variations, this group of stars has been divided into two subgroups, those whose light-variations resemble that of SS Cygni and those which behave similarly to Z Camelopardalis. The SS Cygni group represents the stars of greater regularity in the variations of light, whereas those belonging to the Z Camelopardalis group may be quite regular for long intervals of time and then become erratic.

The stars forming the SS Cygni subgroup are found to form three classes: those whose average periods fall between 97 and 340 days, those whose periods are from 50 to 78 days, and those whose periods are from 13 to 26 days. For the group with the shortest periods the range in brightness is smallest, while for the longer periods the ranges are propor-

* *Contributions from the McDonald Observatory, University of Texas*, No. 69.

[1] *Harvard Circ.*, No. 12, 1896.

[2] *Pop. Astr.*, **49**, 445, 1941.

tionally greater. This was pointed out by Kukarkin and Parenago,[3] who found that the amplitude expressed in magnitudes is proportional to the logarithm of the period. The relationship includes the recurring novae, as well as the U Geminorum variables. It has been suggested that an extrapolation of this formula leads to periods of the order of several thousand years for the normal novae and that they, too, might be cyclical.

Owing to the faintness of this group of variable stars, very little is known about them other than their variations in light. The average brightness of the class at minimum, or normal light, is near 15 mag. The brightest of the group, SS Cygni, is 12.0 mag. at minimum light.

P. Parenago and B. Kukarkin,[4] in discussing the published proper motions of SS Cygni and U Geminorum, have arrived at the following probable parallaxes: SS Cygni, 0".0376, and U Geminorum, 0".0162. They adopt as the mean absolute magnitude of the variables at minimum, +10 mag. ±3 mag. The color indices of SS Cygni and U Geminorum, determined by B. P. Gerasimovič and Cecilia H. Payne[5] at minimum light, are +0.3 mag. and +0.6 mag., thus indicating stars of spectral types F and G. These data would indicate stars several magnitudes in brightness below that of stars on the main sequence. Such values of the parallax should be detectable by trigonometric means; and A. van Maanen,[6] from observations with the 60-inch reflector of the Mount Wilson Observatory, finds absolute parallaxes of −0".012 and +0".010, respectively, for SS Cygni and U Geminorum. He concludes that it is doubtful that the stars should be considered as dwarfs.

The spectra of SS Cygni and SS Aurigae were observed by W. S. Adams and A. H. Joy,[7] of the Mount Wilson Observatory, in 1921. SS Cygni was found to have faint absorption lines of hydrogen and helium 20 A wide at maximum light and emission lines at minimum light. At maximum light SS Aurigae also had faint absorption lines of hydrogen and helium. In 1940 A. H. Joy[8] published additional spectroscopic observations of this class of variables, adding to the list U Geminorum, X Leonis, and SU Ursae Majoris. These were observed at maximum and were found to have continuous spectra without lines of any kind. RU Pegasi at maximum had a continuous spectrum with fairly strong emission lines of hydrogen and helium. Joy observed this star at minimum light and found it to be quite different from that of SS Cygni at the same phase. Wide emission lines of hydrogen and helium were observed on an absorption spectrum of type dG3. The dwarf characteristics were well marked, and the estimated spectroscopic absolute magnitude was +4.7. The stars RX Andromedae, Z Camelopardalis, and 90.1934 Draconis were observed at maximum and found to have continuous spectra with faint emission lines of hydrogen.

We have observed as many of the stars of this class as possible with the spectrographs attached to the 82-inch telescope. In nearly all classes we have utilized the highest dispersion feasible. Two spectrographs have been employed, the large Cassegrain spectrograph and a small one designated as the "K" spectrograph. The latter has glass optics and a camera 35 mm in focal length. The combination gives a linear dispersion of 340 A/mm at $H\gamma$. The large spectrograph may use either glass or quartz prisms and either of two Schmidt cameras: one with a focal length of 180 mm and an aperture ratio of f/2, and the other with a 90-mm. focal ratio and an aperture ratio of f/1. Throughout the remainder of the paper we shall use the following designations for the various combinations of the Cassegrain spectrograph: F/1Q for the 90-mm Schmidt camera and the quartz prisms; F/1G for the same with the glass prisms; F/2Q for the 180-mm Schmidt camera and quartz prisms; and F/2G for the same camera and the glass prisms. The linear dispersions of the spectrograms at Hγ for the various combinations are: F/1Q, 340 A/mm; F/1G, 150 A/mm; F/2Q, 170 A/mm; and F/2G, 75 A/mm.

[3] *Nijni Novgorod Var. St.*, **4**, 251, 1934.

[4] *Ibid.*, p. 249.

[5] *Harvard Bull.*, No. 889, p. 3, 1932.

[6] *Ap. J.*, **87**, 424, 1938.

[7] *Pop. Astr.*, **30**, 103, 1922.

[8] *Pub. A.S.P.*, **52**, 324, 1940.

The stars which we have observed are listed in Table 1. They have been grouped according to the subdivision to which they have been assigned. Those definitely assigned to the SS Cygni subdivision are listed first, then those assigned to the Z Camelopardalis group, and, last, the ones whose classification is uncertain. In the last group are included some miscellaneous objects which should not be included as members of the U Geminorum class of variable stars, but descriptions of their spectra are given, since the objects were on our program.

SS CYGNI VARIABLE STARS

UU Aquilae.—This star is normally faint, 16.8 mag., and, consequently, we have only one spectrogram of it with the K-spectrograph obtained on JD 2430122 when the star was approximately 15 mag. The spectrum is practically a continuous one with no absorption lines. *Hα* is moderately strong, but there is no evidence of additional emission lines. The distribution of the intensity in the continuous spectrum is similar to that of spectral class G.

TABLE 1

U GEMINORUM STARS OBSERVED

Star	Harvard Designation	Mag.	Period	Class	No. of Obs.
UU Aql	195209	11.0–16.8	30 –> 80	SS	11
SS Aur	060547	10.5–14.7	25 –103	SS	4
SS Cyg	213843	8.1–12.0	50.3	SS	23
U Gem	074922	8.8–13.8	62 –257	SS	10
X Leo	094512	12.0–15.1	19	SS	5
AY Lyr	184137	12.5–>14.5	21:	SS	3
RU Peg	220912	9.0–13.1	38 –97	SS	4
SU Uma	080362	11.1–14.5	18 –22	SS	4
TW Vir	114003	11.8–15.8	23:	SS	3
RX And	005840	10.3–13.9	14	Z	10
Z Cam	081473	9.6–13.3	23	Z	19
AH Her	164025	11.2–14.1	19	Z	3
CN Ori	*054705*	11 –14.7	19.2	Z	4
TZ Per	020757	12.4–15.3	.....	Z	2
EY Cyg	195032	.....	.....	.....	1
CY Lyr	184926	12 –16	.....	.....	3
CO Ori	052211	10.4–12.9	.....	Irreg.	1
UX Ori	*045903*	9.2–10.0	.....	Irreg.	1
CL Sco	*164830*	11.1–13.5	.....	.....	2
T Pyx	*090032*	6.5–14.1	.....	Nova	1
V Sge	201520	9.5–13.2	.....	Ex-nova	6

SS Aurigae.—Four spectrograms of this star were obtained during the maximum of November 15–17, 1940. Three of them were obtained with the F/2G spectrograph and are of good quality. All show a continuous spectrum without a trace of an absorption line, and only one of them shows the faintest trace of *Hα* emission. If it were not for the excellent quality of the spectrogram, the emission line would not have been distinguishable. The color of the continuous spectrum is certainly that of an early A- or B-type star.

SS Cygni.—This star has been observed more frequently than all the others, since at minimum phase it is the brightest of this class of variable stars. We have been able to obtain some spectrograms at all phases, using the F/2G spectrograph; however, a large number have been obtained with the F/2Q. Figure 1 gives a plot of its brightness as ob-

served by the American Association of Variable Star Observers.[9] The lines indicate the dates of the spectrograms.

There is not sufficient material to discuss in detail the spectral changes through various types of maxima; hence we shall group the data according to the four principal phases of the light-variation: minimum, increase, maximum, and decrease.

The minimum for this class of variable stars appears to be the normal condition of the star, and we shall start with it. At this time SS Cygni shows a faint continuous spectrum, upon which is superimposed an emission spectrum. The distribution of light in the continuous spectrum, when compared with a set of standard spectra, is found to be similar to that of dG5 or later spectrum, thus indicating a low temperature. There is no evidence on any of our spectrograms of an absorption spectrum other than possibly the *Na* D lines, and hence any classification of the star must be done from the distribution of intensity in the continuous spectrum.

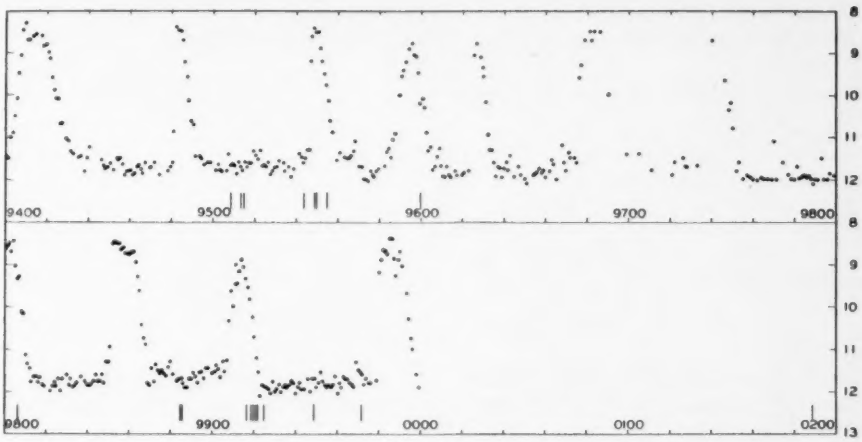


Fig. 1.—Light-curve of SS Cygni. The lines below the observations show the dates on which spectrographic observations were made.

The emission spectrum of SS Cygni is the strongest of any of this class of stars which we have observed. The hydrogen lines are very strong and can be traced to *H*9 or *H*10, where they merge into the continuous hydrogen emission (Fig. 2). The lines of the 2^3P-n^3D series of helium λλ 5875, 4471, and 4026 are quite prominent, but most of the other helium lines are faint. The following additional helium lines have been identified on the better spectrograms: 2^1S-n^1P, λ 5015; 2^1P-n^1D, λ 4921, λ 4387; and possibly 2^3P-n^3S, λ 4713 and λ 4120. The calcium line, K, is about of the same intensity as λ 4026 of helium.

On the spectrograms of lower dispersion the emission lines of hydrogen are wide but appear to have fairly sharp edges. However, we have two spectrograms at minimum light taken with the F/2G spectrograph, and the dispersion is sufficient to show that the emission lines are far from being sharp and that they possess extensive wings. We have obtained the profiles of *Hβ*, *Hγ*, *Hδ*, and *He* I 4471, which are illustrated in Figure 3. The relative intensities are valid only within a given line; and it will not be possible to compare the relative intensities of the various members of the series until the background continuous spectrum of the star has been measured against some standard. Exponential curves are fitted to the observations of the hydrogen lines. The projected slit widths for *Hβ*, *Hγ*, *Hδ*, and *He* I 4471 are 3.2 A, 2.0A, 1.6A, and 2.3A, respectively.

[9] *Pop. Astr.*, **49**, 95, 1941.

The four hydrogen lines, $H\beta$–$H\epsilon$, are of nearly the same brightness; the average is 1.20 mag. brighter than the continuous spectrum. The helium line λ 4471 is 0.5 mag. brighter than the continuous spectrum, the calcium line, K, 0.25 mag., while the fainter helium lines are about 0.2 mag. The faint helium lines on this spectrogram are at the limit of detectability; however, if a spectrogram were such that the density was on the steeper part of the characteristic curve, we estimate that it might be possible to distinguish a line which is 0.1 mag. brighter than the continuous background.

We were unable to get observations during the increase in light, but during this time there must be a transition in which the color of the continuous spectrum becomes bluer as it brightens and the emission lines must become relatively fainter.

We have three observations at the peak of the maximum on JD 2429548–49. Two were taken with the F/2Q spectrograph and the other with the F/2G. The change in the spectrum from minimum to maximum is very marked. The spectrum is almost a continuous one, and it is only with difficulty that we can detect three or four of the hydrogen lines in emission. The emissions are rather narrow and appear as if they were only the tips of the former emissions, which were visible at minimum. Relative to the continuous

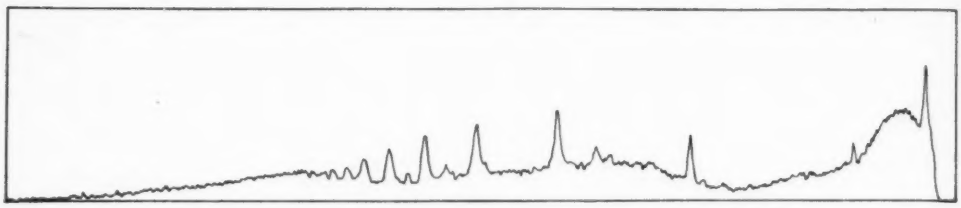


Fig. 2.—Tracing of the spectrum of SS Cygni at minimum light

spectrum, we estimate that these hydrogen lines are roughly of the same intensity as the fainter helium lines reported for the star at minimum light; thus they are about 0.2 mag. brighter than the background.

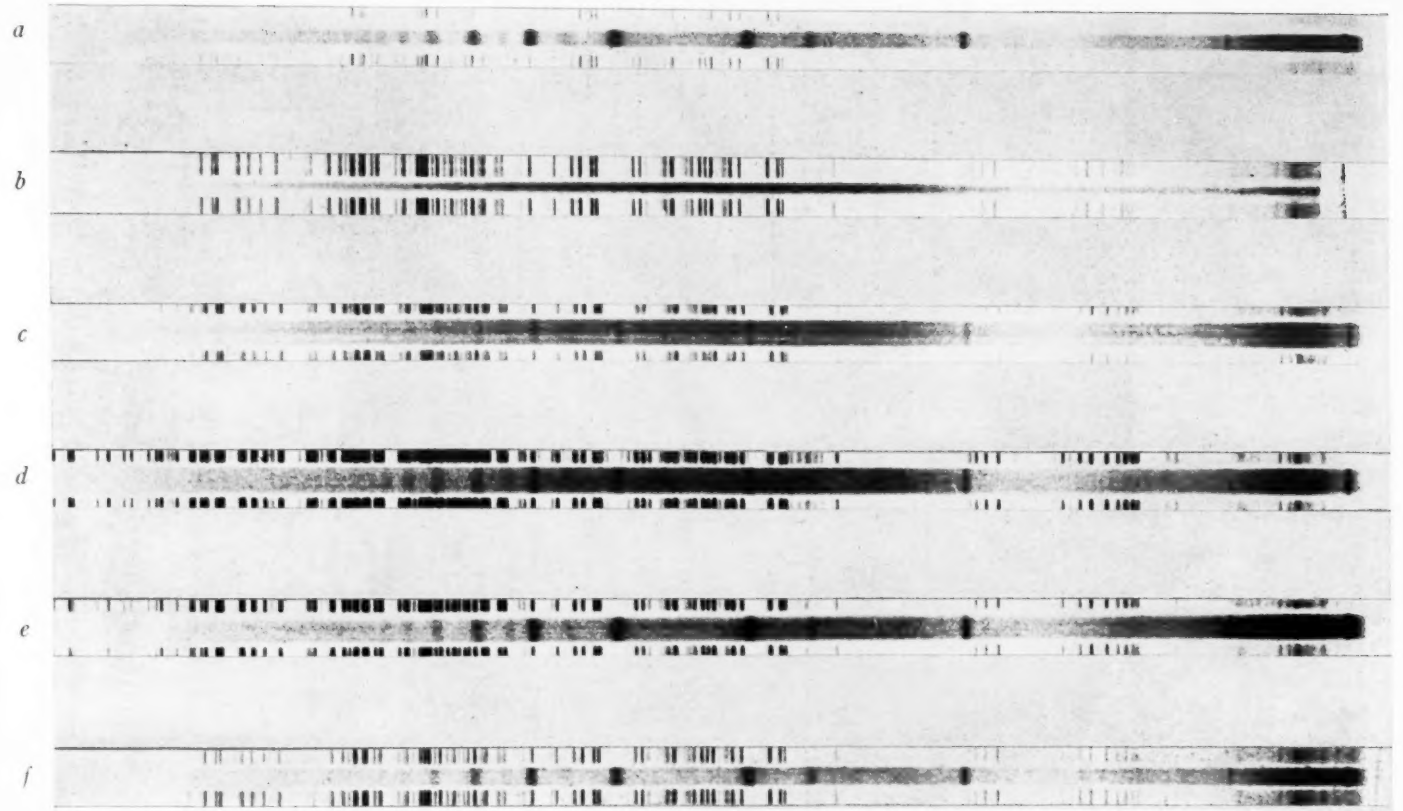
Since we know that the hydrogen lines were 1.20 mag. brighter than the continuous spectrum at minimum light, we can compute the masking effect of an increase in the continuous spectrum, assuming that the intensity of the emission remains the same. An increase of 3 mag. will leave the emission lines with a residual intensity of 0.19 mag., and an increase of 4 mag. will leave the intensity 0.07 mag. We note from the light-curve (Fig. 1) that the magnitude of the star when the intensities were measured for minimum, JD 2429543, just prior to the increase in brightness, was 11.5 mag., while the maximum a few days later for which we have spectrograms is 8.5 mag., corresponding to an increase of 3 mag. Thus we see that the increased brightness of the continuous spectrum of the star is sufficient to account for the disappearance of the emission lines at maximum. W. S. Adams and A. H. Joy[7] have reported wide, diffuse absorption lines in SS Cygni at maximum. The changing conditions of the star and the surrounding atmosphere of hydrogen might easily account for the difference between their observations and ours.

By comparing the continuous spectrum with those of standard spectra we find that at maximum the distribution is very similar to that in a star of early B type. Thus the continuous spectrum corresponds to a large range in temperature from minimum to maximum light.

At maximum an additional emission feature makes its appearance at the position of the ionized helium line λ 4686. It is very weak and of roughly the same order of intensity as the hydrogen lines at this stage.

During the decline in light we have a very good series clustering around JD 2429920. These spectrograms show a progressive change of the spectrum from that of maximum to that of minimum. The continuous spectrum gradually changes back to its former color;

PLATE XXXII



SPECTRA OF SS CYGNI

a) JD 2429508, minimum light
b) JD 2429548, maximum light
c) JD 2429918, decreasing light
d) JD 2429920, decreasing light
e) JD 2429921, decreasing light
f) JD 2429513, minimum light

the emission lines become brighter as the brightness of the star decreases; and the faint emission of ionized helium remains very faint through most of the decline, but apparently is absent after the star reaches minimum light. The progression of changes in the spectrum of SS Cygni is shown in Plate XXXII.

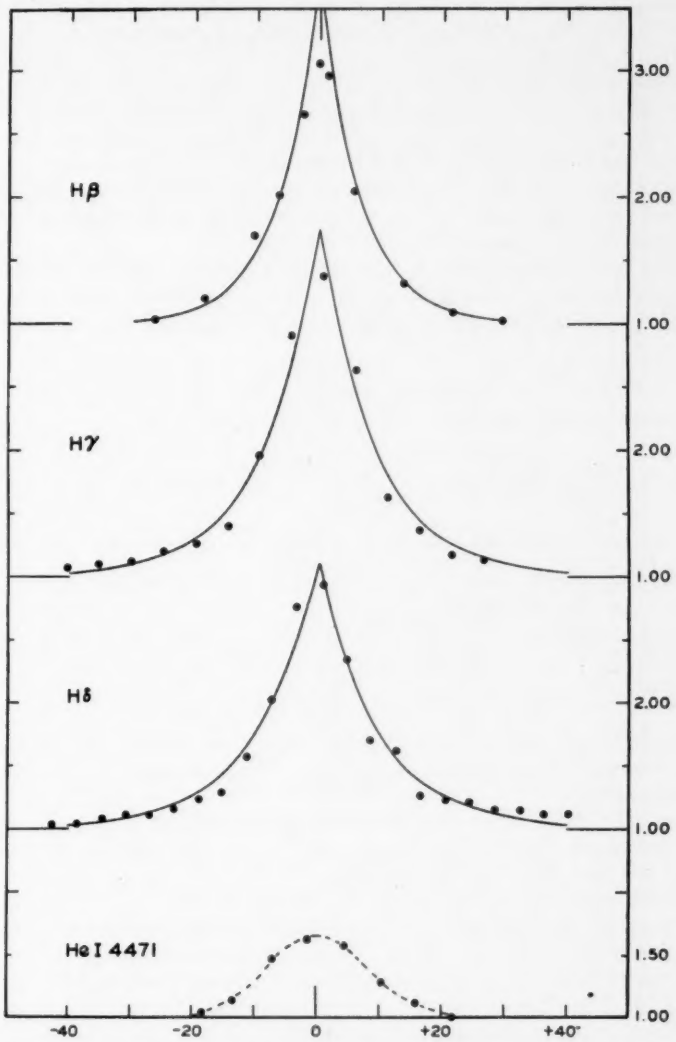


Fig. 3.—Profiles of the emission lines $H\beta$, $H\gamma$, $H\delta$, and *He* I 4471 in the spectrum of SS Cygni. Exponential curves have been drawn through the observed points of the hydrogen lines.

The radial velocity of SS Cygni as represented by the centers of the emission lines appears to be variable; however, a portion of this must be attributed to possible errors of measurement, since the lines are wide and the linear dispersion is rather small for some of the observations. The velocities are listed in Table 2, which gives the dates of the observations and the spectrographs employed. The mean half-widths of the emission lines expressed in km/sec are also included in the table. The mean for all determinations gives the radial velocity as −62 km/sec and the mean half-width as 424 km/sec.

U Geminorum.—U Geminorum is one of the group with the longer average periods between eruptions. The light-variations for this star follow a quite regular pattern and do not show any of the erratic fluctuations common to those of shorter period or of the Z Camelopardalis subgroup.

We have obtained only two spectrograms with low dispersion of this star at minimum light and then a group of eight spectrograms around the maximum of light in February, 1940, JD 2429678. At minimum light there is a continuous spectrum on which are superimposed emission lines. The distribution in the light of the continuous spectrum is similar to that of a late G-type dwarf star if one compares the red and blue regions of the spectrum; there appears to be a considerable extension into the violet, but this is probably a result of the continuous hydrogen emission which begins at *H*7.

The hydrogen emission lines are strong, as in SS Cygni. The low dispersion and resolving-power do not permit us to make a good estimate of the widths of the lines. The merging of the hydrogen emission lines at *H*7 to form the continuous hydrogen emission may be due also to the low resolution. The stronger helium lines and the calcium line, K, are present in emission; the fainter ones would not be visible on this dispersion, and it appears that the spectrum is very much like that of SS Cygni. One of the spectrograms

TABLE 2

RADIAL VELOCITIES OF SS CYGNI

JD 2420000+	Velocity (Km/Sec)	Mean Half-Width (Km/Sec)	Spectrograph	JD 2420000+	Velocity (Km/Sec)	Mean Half-Width (Km/Sec)	Spectrograph
9508	− 90	400	F/2 Q	9919	− 49	400	F/2 Q
9513	−168	428	F/2 Q	9920	−42	445	F/2 Q
9543	+ 42	455	F/2 Q	9921	+ 5	432	F/2 Q
9806	− 78	400	F/2 Q	9924	−24	430	F/2 Q
9884	− 88	505	F/2 Q				
9885	−150	475	F/2 Q	Mean	−62	424	.....
9918	− 40	(295)	F/2 Q				

was taken on JD 2429673, just before the star began its rise to a maximum. We estimated the brightness as 13.7 mag. The emission lines appear considerably fainter than on the other spectrogram.

At maximum light we were able to obtain spectrograms with both the F/2Q and F/2G spectrographs, using the Agfa Super Pan Press emulsion, and also with the F/2Q spectrograph, using an Eastman Process film. With the high-contrast emulsion we cannot see any evidence of absorption lines at maximum. On the panchromatic emulsions we see a fairly strong $H\alpha$ and a very faint $H\beta$, but the other members of the series are absent. The ionized helium line, λ 4686, is present at maximum. Two spectrograms were obtained after the star had decreased in brightness three-fourths of a magnitude and two additional hydrogen lines had become very faintly visible (Fig. 4). The distribution of light in the continuous spectrum at maximum corresponded closely to that of a star of spectral class B5.

X Leonis.—The variable X Leonis belongs to the group of short-period SS Cygni stars; its period is about 19 days. At maximum brightness it barely reaches the twelfth magnitude. We have four spectrograms with the F/1Q spectrograph and one with the K spectrograph, all of which are at the maximum light of the star. The brightness ranges from 12.4 mag. to 13.0 mag. for these observations.

The distribution of the light in the continuous spectrum resembles that of a late A-type, or an F0, star. Thus, at maximum, it has a temperature considerably lower than that of either U Geminorum or SS Cygni.

In the regions of $H\alpha$ and $H\beta$ the spectrum appears to be continuous, but $H\gamma$, $H\delta$, and $H\epsilon$ are definitely absorption lines. The lines are wide, diffuse, and faint, very much as might be expected for a star with high rotational velocity or lines greatly widened by Stark effect.

AY Lyrae.—This star is another of the short-period group of the SS Cygni subclass, and we have obtained two spectrograms of it at minimum light with the K spectrograph. Until the spectrograms of this star were obtained, we had considered emission lines a necessary feature in the spectra of this class of variable stars at minimum light. Hence, when none was found on the first spectrogram, we suspected that the wrong star had been taken. A careful check revealed that this was not the case, as a second spectrogram also showed the absence of an emission spectrum. Instead, an absorption spectrum was found; both the H and K lines of calcium and the G band are faintly present. The quality of the spectrograms is not good enough to give more than a crude classification as that of spectral type G.

RU Pegasi.—RU Pegasi belongs to the class of SS Cygni stars with intermediate periods. Its period varies between 38 and 97 days, and apparently it is a very erratic star. Campbell and Jacchia[10] say, "RU Pegasi is a curious star which is irregular most of

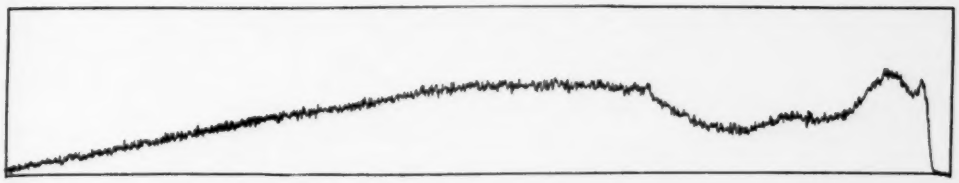


FIG. 4.—Tracing of the spectrum of U Geminorum on February 23, 1940, just after maximum light

the time and only on rare occasions does it qualify as a regular U Geminorum star." We have observed it four times when it was at or near minimum light; the brightness was 12.4–12.6 mag. Spectrograms with both the F/1Q and F/2Q spectrographs have been obtained.

On the spectrogram of higher dispersion we see a faint continuous spectrum containing some of the stronger metallic absorption lines and an emission spectrum of hydrogen and helium. A. H. Joy[8] has classified the spectrum as dG3, but we are somewhat reluctant to give it a definite classification, owing to the faintness of the absorption features which have the appearance of being masked. The calcium line λ 4226 is possibly present, thus indicating an A- or F-type spectrum, but the distribution of the intensity in the spectrum distinctly resembles a late G type. The sodium lines appear beside the helium emission line λ 5875. Seven of the Balmer lines of hydrogen are in emission; the helium lines λλ 5875, 4471, and 4026, and the ionized calcium line, K, are faintly visible.

SU Ursae Majoris.—This is another of the variables with short cycles—the time between maxima usually ranges from 18 to 22 days, and the brightness varies from 14.5 mag. at minimum to 11.1 mag. at maximum. We have obtained spectrograms of the star with the F/1Q spectrograph when the star was 12.0, 13.2, and 13.8 mag. on successive nights decreasing from maximum, and with the K spectrograph when it was at minimum, 14.5 mag.

The spectrogram of SU Ursae Majoris taken at the twelfth magnitude is similar to that usually found at maximum for these stars. It is essentially a continuous spectrum, the color representing a B5-type star. A very faint emission of $H\alpha$ is present, but there are no other emission or absorption features. The spectra of the two following nights are those usually associated with decreasing light, that is, the emission lines become more

[10] *The Story of Variable Stars*, p. 153, 1941.

prominent and the continuous spectrum becomes redder. At minimum light there are six or seven hydrogen emission lines of medium intensity. The helium lines are very faint, while the calcium line, K, is slightly more intense. There is a very slight indication of the presence of the G absorption band, but the low dispersion prevents the detection of many of the absorption lines.

TW Virginis.—TW Virginis has a mean cycle of approximately 23 days. At minimum it is 15.8 mag., and at maximum it reaches 11.8 mag. We have one fairly good spectrogram of the star with the K spectrograph when it was near the fifteenth magnitude and two others that are underexposed. The continuous spectrum was rather faint and contaminated with sky light, especially in the blue region; and consequently we can tell very little concerning the distribution of its light with regard to wave length and as to possible absorption lines in the spectrum. The G band seems to be in absorption, but this may be the spectrum of the zodiacal light. A part of the slit of the spectrograph was exposed to the sky in order to record the intensity of the sky light when long exposures were given or when there was moonlight or zodiacal light.

The emission spectrum consists of six hydrogen lines, *He* I 4471 and possibly *Ca* II 3933 (K).

Z CAMELOPARDALIS VARIABLE STARS

The next group of stars is the Z Camelopardalis subgroup. Whenever they go through their regular variations, they behave very similarly to the shorter-period group of SS Cygni stars. However, these stars may remain for weeks at a relatively constant brightness, approximately one-third of the way from maximum to minimum.

RX Andromedae.—During the period for which we have observations of this star, it has been in one of its relatively constant stages, and there have been only minor fluctuations in its light.[11] We have estimated the brightness at each observation, and during the period November 13, 1939—October 18, 1940 it has varied between 11.5 mag. and 12.5 mag. The spectrograms will be described separately.

JD 2429579, 11.5 mag.—A very weak spectrogram obtained with the F/2 spectroraph, which barely shows the continuous spectrum. Six of the hydrogen lines can be distinguished in emission.

JD 2429657, 11.5 mag.—A well-exposed spectrogram obtained with the F/1Q spectrograph, which shows six or seven hydrogen emission lines faintly. No absorption features are visible.

JD 2429881, 12.5 mag.—An excellent spectrogram obtained with the F/1Q spectrograph. The hydrogen emission lines are fairly strong and can be traced to *H*9. The *Ca* II K line is faintly visible in emission, but no helium lines are seen.

JD 2429882, 12.1 mag.—Another spectrogram obtained with the F/1Q spectrograph; but the emission lines of hydrogen are weak relative to the continuous spectrum, and only four members can be seen.

JD 2429883, 12.0 mag.—This observation was with the F/2Q spectrograph. Only four weak hydrogen emission lines can be seen.

JD 2429884, 11.6 mag.—A spectrogram with the F/1Q spectrograph is in focus only for the region λλ 3900–4100. $H\delta$ and $H\epsilon$ are well visible in emission and are no wider than the comparison spectrum lines.

JD 2429891, 11.6 mag.—A spectrogram of fair quality, using the F/2Q spectrograph, was obtained, which shows five or possibly six hydrogen emission lines.

JD 2429919, 11.5 mag.—This spectrogram with the F/2Q spectrograph is of good quality and shows faintly five hydrogen emission lines.

JD 2430187, 11.8 mag.—This is a good spectrogram taken with the F/1Q spectrograph, and the spectrum is almost continuous with the exception of a very faint emission line at $H\alpha$. The region of $H\alpha$ on this emulsion is very weak.

[11] *Pop. Astr.*, **49**, 332, 1941.

The color of the spectrum during most of this time was similar to that of a late A-type star.

Z Camelopardalis.—This is the type star for the subgroup, and we have been able to obtain a fairly good series of observations covering the regular period of the star. The light-curve during the period for which we observed the star is shown in Figure 5; the dots are the observations by the members of the American Association of Variable Star Observers,[12] while the circles are our own estimates of its brightness. The lines in the lower portion of the diagram show the dates on which we have spectrographic observations.

At minimum light this star has a continuous spectrum whose color is very similar to that of a dG5 star; however, there are no absorption lines in the spectrum on the low dispersions which we have used at this phase. There is a fairly strong emission spectrum of hydrogen in which seven or eight lines are visible before it merges into the continuous

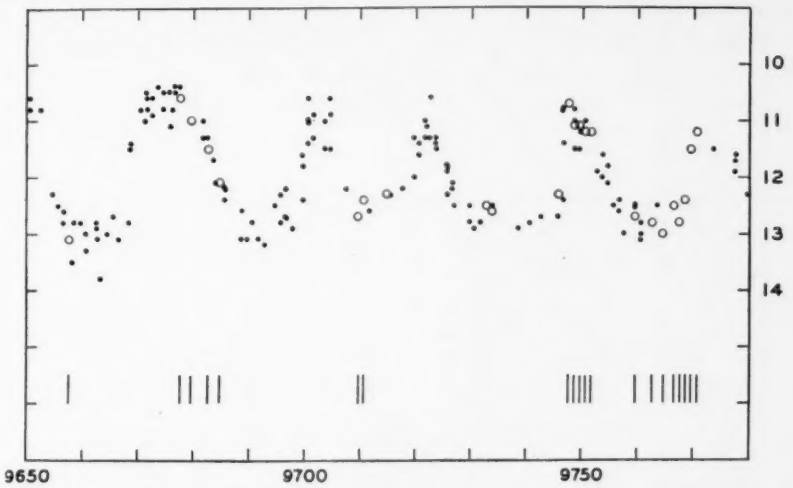


FIG. 5.—Light-curve of Z Camelopardalis. The lines below the observations show the dates of spectrographic observations.

hydrogen emission. The helium emission is very faint, only λ 5875 and λ 4471 being identified on one or two spectrograms. The calcium emission line, K, is slightly stronger. The emission lines in this star are very wide.

We have three spectrograms during the increase of light, one as the star has started brightening and two near the top of the weak maximum at JD 2429770. The first is very much underexposed but shows faintly three emission lines of hydrogen, and the other two show the presence of very wide, shallow, and diffuse hydrogen absorption lines. There is no evidence of emission lines on either of the two latter spectrograms.

At maximum light we have six spectrograms, one on JD 2429677.6 at the end of the broad maximum, another on JD 2429747.7, and a group of four which are situated on the slight halt in the light-curve around JD 2429750, before descending to minimum.

The spectrogram obtained on JD 2429677.6 was with the F/1Q spectrograph and was somewhat overexposed. It shows only a continuous spectrum with a suggestion of a double emission near *He* II 4686. The spectrogram taken on JD 2429747.7 was with the F/2G spectrograph and was underexposed. Only a continuous spectrum is visible; however, fainter absorption and emission features would be missed. The four observations grouped around JD 2429750 are good spectrograms, one with the F/2G spectrograph

[12] Campbell and Jacchia, *op. cit.*, p. 158.

and the others with the F/2Q spectrograph. The spectrum is principally a continuous one; however, the emission lines of hydrogen are beginning to appear, and on the last spectrogram five of the Balmer lines can be seen. The *He* II 4686 line is faint on the first of the spectrograms but is absent on the remainder. The spectrogram taken on JD 2429750.7 shows faint absorption lines to the violet side of $H\beta$, $H\gamma$, and $H\delta$. However, the microphotometric tracing shows absorptions also on the red sides. We have measured the positions of the absorption lines and find that they correspond to a velocity of −800 km/sec. The centers of the emission lines give a velocity of −133 km/sec. The measured half-widths of the emission lines give a mean of slightly over 600 km/sec when expressed in units of velocity. This is about 50 per cent larger than was found for SS Cygni.

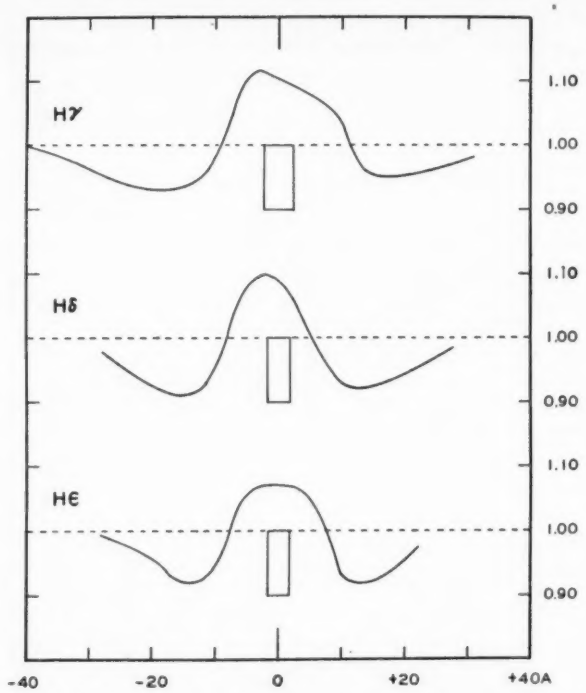


FIG. 6.—The profiles of the hydrogen lines in the spectrum of Z Camelopardalis on JD 2429750. The widths of the rectangles give the effective slit widths on the spectrogram.

The profiles of the hydrogen lines in Z Camelopardalis on JD 2429750 are shown in Figure 6. As will be seen from the scale of ordinates, the vertical scale has been greatly magnified. The emission lines seem to be superimposed upon very wide absorption lines which have the appearance of having been widened through high rotation of the star. The emissions appear to be only the tips of the emission lines as observed at minimum light. An inspection of a microphotometer tracing of a spectrogram of slightly lower resolving-power taken at minimum light shows that the emission lines are practically of the same width as the underlying absorption lines of Figure 6. This would indicate, if the edges of the wide lines are a result of a velocity displacement, that the velocities, as represented by the absorption and the emission, are of the same order of magnitude. During the decrease to minimum light the hydrogen emission lines become stronger relative to the continuous spectrum and can be seen to $H\epsilon$. No other emission or absorption lines can be seen.

AH Herculis.—AH Herculis and the following star, CN Orionis, are included as Z Camelopardalis variable stars, since they go through semiregular variations as the type star occasionally does and there is no other place for them in the listing of types.[13]

We have obtained three spectrograms of AH Herculis with the K spectrograph when the star was at minimum brightness. The spectrum looks very much like that of other SS Cygni or Z Camelopardalis stars at minimum light. The continuous spectrum has a color resembling that of a G-type star, and there is an emission spectrum of hydrogen. Seven of the Balmer lines were seen, which is the limit that might be expected from the glass optics.

CN Orionis.—CN Orionis has a mean cycle of 19.2 days, with the minimum below fourteenth magnitude and the maximum around the twelfth magnitude. We have three spectrograms with the F/1Q spectrograph when the star was at or near maximum. One good spectrogram taken when the star was 12.1 mag. shows a continuous spectrum with very wide, shallow absorption lines of hydrogen. The others show only a continuous spectrum.

TZ Persei.—Two spectrograms of this star were obtained at or near maximum light, JD 2429919–20, when the brightness was estimated at 13.0 mag. The spectrum is a continuous one, and the color is approximately that of an A5 star.

OTHER VARIABLE STARS

The following stars are unclassified among the two groups of U Geminorum variables; also included are one or two irregular variables and ex-novae for which spectroscopic observations were desirable.

EV Cygni.—This object is suspected of belonging to the U Geminorum class of variable stars. Its brightness varies from 16.0 mag. to 11.5 mag. We have only one observation of it with the K spectrograph on JD 2420169, when its brightness was estimated to be 14.5 mag. Our spectrogram shows only a faint continuous spectrum whose color is approximately that of spectral class G. The only lines visible in the spectrum are the emission lines of the night sky.

CY Lyrae.—CY Lyrae belongs to the U Geminorum class, but it is not certain to which subgroup. Its cycle varies from 10 to 20 days and the brightness from 16 mag. to 13.0 mag. We have observed it with the F/1Q spectrograph on JD 2429919, obtaining two spectrograms when it was at maximum brightness, and again with the K spectrograph on JD 2430122, when the brightness was estimated 13.8 mag. The first two spectrograms were of fair quality but showed only a continuous spectrum. The last one, of low dispersion, had very wide, diffuse, and shallow absorption lines at $H\gamma$, $H\delta$, and $H\epsilon$. The distribution in the continuous spectrum is quite similar to that of an early A-type star.

CO Orionis.—This star is an irregular variable which varies between 12.9 mag. and 10.4 mag. We obtained one spectrogram with the F/2Q spectrograph on JD 2429925. The color of the continuous spectrum approximates that of a dK0 star. There is a faint metallic absorption spectrum which is similar to that of an early F-type star; however, the *Ca* II H and K and the hydrogen lines are abnormal. $H\alpha$ is quite bright, and at $H\beta$ the spectrum is practically continuous. $H\gamma$ and $H\delta$ are faint, rather narrow absorption lines. The region of *Ca* II is underexposed, but it appears as though there are two faint emission lines superimposed on rather wide, shallow absorptions. The spectrum of this star should be investigated in more detail.

UX Orionis.—UX Orionis is another irregular variable whose range is from 10.5 to 9.2 mag. We have one spectrogram of excellent quality of this star with the F/2Q spectrograph. The spectrum resembles very closely that of spectral class A2 or A3, but with $H\alpha$ in faint emission.

[13] *Harvard Bull.*, No. 852, 1927.

CL Scorpii.—This variable star was discovered by Luyten and announced as probably belonging to the U Geminorum class. Miss Swope[14] from many more observations has stated that the star is "more nova-like than of the SS Cygni type." We have obtained two spectrograms of this star with the K spectrograph. They show a continuous spectrum, upon which is superimposed a strong emission spectrum of hydrogen. Both the helium line λ 5875 and the ionized helium line λ 4686 are present, as well as two or three fainter lines which have not been identified, owing to the low dispersion. The star was estimated to be 13 mag. at the time of the observations.

T Pyxidis.—We have obtained one underexposed spectrogram with the K spectrograph of this recurring nova. It shows a faint continuous spectrum, and there are no emission lines that are strong in comparison to the continuous spectrum. The star was estimated to be approximately of the fifteenth magnitude.

V Sagittae.—V Sagittae, probably an ex-nova, is a star that we have observed on several occasions, and we are including it here to give a preliminary report on the spectrum. V Sagittae is rather erratic in its light-variations; but sometimes two periods—one of 17 days and the other of 530 days—have been found. Most of our observations are at the time when the star rose in brightness to around the eleventh magnitude in September and October, 1940. One observation was taken in March, 1940, when it was 12.4 mag.; and in June, 1941, we have two observations when the estimated brightness was 12.5 mag.

In March, 1940, the spectrum was mainly a continuous one with a fairly strong *He* II 4686 emission line and emission lines of hydrogen, which are not very strong. *Hα* and *Hβ* are barely visible. *He* I 5875 and possibly *He* I 4471 are present in emission. The distribution of intensity in the continuous spectrum is similar to that of an early B-type star. By September the star had brightened 1 mag., and during the month we obtained three spectrograms, one with the F/1Q spectrograph and two with the F/2Q spectrograph. These spectrograms show a distinct increase of intensity of the emission lines; the *He* II 4686 line is now quite strong, and the hydrogen emission lines are more distinct, at least five of the series being visible. One of the spectrograms with the F/2Q spectrograph is of excellent quality and shows an interesting structure. The total width of the emission lines is about 40 A, but the red halves are strong, and the violet halves are weak. The two portions of the lines have rather sharp edges, and the intensity across either half appears fairly uniform. The position of the division between the two parts is approximately 4 A to the violet of the normal position of the line. The spectrograms have not been measured, and several faint lines which are present have not been identified. In October, 1940, we have two spectrograms with the star at about the same brightness as it was in September, and there appear no major changes in the spectrum; however, the quality is not so good as the best spectrogram of the previous month. On June 16, 1941, we obtained a good spectrogram with the F/2G spectrograph, when the estimated brightness of the star was 12.5 mag. The intensities of the emission lines were somewhat decreased, and the violet halves of the complex lines present in September are no longer visible. The red portion of the line is approximately in the same position.

SUMMARY

It is perhaps too early to make generalizations from the observational material of the U Geminorum stars, since we do not have spectrographic observations for many of the objects at all phases of their cycles. However, many of the stars are similar. Hence we shall give a brief summary of the characteristics at the different phases of the cycle, though it is necessary to call attention to several exceptions.

At minimum, or normal, light the U Geminorum variable stars have a continuous spectrum with few or no absorption features, and superimposed on this are wide emission

[14] *Ap. J.*, **94**, 140, 1941.

lines of hydrogen, helium, and ionized calcium. The hydrogen lines are the most pronounced features, while the helium and calcium lines are often quite faint. The calcium line is of about the same intensity as the fainter helium lines. The continuous hydrogen emission is present on many of the well-exposed spectrograms obtained with the quartz optics. The absence of absorption features makes it impossible to classify the spectra, but crude estimates of the color classes have been made by comparing the distribution of intensity within the continuous spectrum with that of stars of known spectral classes. At minimum light all of the spectra had colors which are similar to stars belonging to spectral class G. Some of the better-determined ones were listed as similar to dG5 stars.

One star, AY Lyrae, did not have an emission spectrum at minimum light. RU Pegasi exhibits an absorption spectrum, as well as wide emission lines of hydrogen and helium. A spectrogram obtained by A. H. Joy showed the dwarf characteristics as well marked, and he estimated the spectral class as dG3.

At maximum light the spectrum has changed very greatly. The emission lines in most cases have disappeared. In many of the stars the spectrum is continuous, while others show faint and very wide, diffuse absorption lines of hydrogen. The shapes of the lines as seen on microphotometer tracings resemble lines which are produced through high axial rotation, but it is premature to say that these lines are thus produced without a detailed investigation. If these lines are produced through rotation of the star, it would appear that the rotational velocities are much higher than would be allowed from stability considerations. On the other hand, these stars do go through a period of instability during their increases in brightness, and possibly this is related to the high rotational velocities.

One of the major changes of the spectrum is the variation in the distribution of intensity in the continuous spectrum. It represents a marked change in temperature. The stars which have the greater increases in brightness appear to have the greater increases in temperature; their colors are similar to that of B-type stars, while those with smaller increases in light have colors similar to that of A-type or early F-type stars. The preliminary evidence indicates that the changes between minimum and maximum for these stars are parallel to the main sequence. However, accurate spectrophotometric observations to determine the temperatures through their cycles for several of these variable stars are still needed.

Measured parallaxes of the U Geminorum type of variable stars are very meager, and additional data are required in order to establish the absolute magnitudes of these objects. A study of the proper motions of SS Cygni and U Geminorum by Parenago and Kukarkin indicated an absolute magnitude of $+10 \pm 3$ for these objects. On the other hand, van Maanen concluded from his measures of the parallaxes that these two stars probably are not dwarfs.

THE SPECTRUM OF PLEIONE*

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Received February 28, 1943

ABSTRACT

The radial velocity of Pleione shows oscillations with a range of 10 km/sec and a period of about four months. The mean velocity is +5.5 km/sec. The spectrum of the shell, first discovered by McLaughlin and Mohler in 1938, has gradually become stronger and now resembles the metallic spectrum of α Cygni. Dilution effects are conspicuous in the weakness of *Mg* II and *Si* II. Among the lines of ions having metastable lower levels, *Ni* II and *Fe* II became conspicuous in 1940, *Ti* II in 1941, and *Mn* II in 1942. This order of development is not consistent with the ordinary theory of ionization, and its explanation must be sought in the conditions of excitation of the metastable levels in the shell. The central intensities of the cores of the *H* lines are about 10 per cent—roughly one-half or one-third of the central intensities of the corresponding lines in α Cygni. This is explained as a consequence of the reduced re-emission which is thrown back within the shell into the emerging beam of radiation from the star. The metallic lines on the violet side of the Balmer limit and between the higher members of the series are relatively much stronger than in α Cygni. This is due to the semitransparency of the shell, on the one hand, and to the absence of Stark effect wings in the shell, on the other.

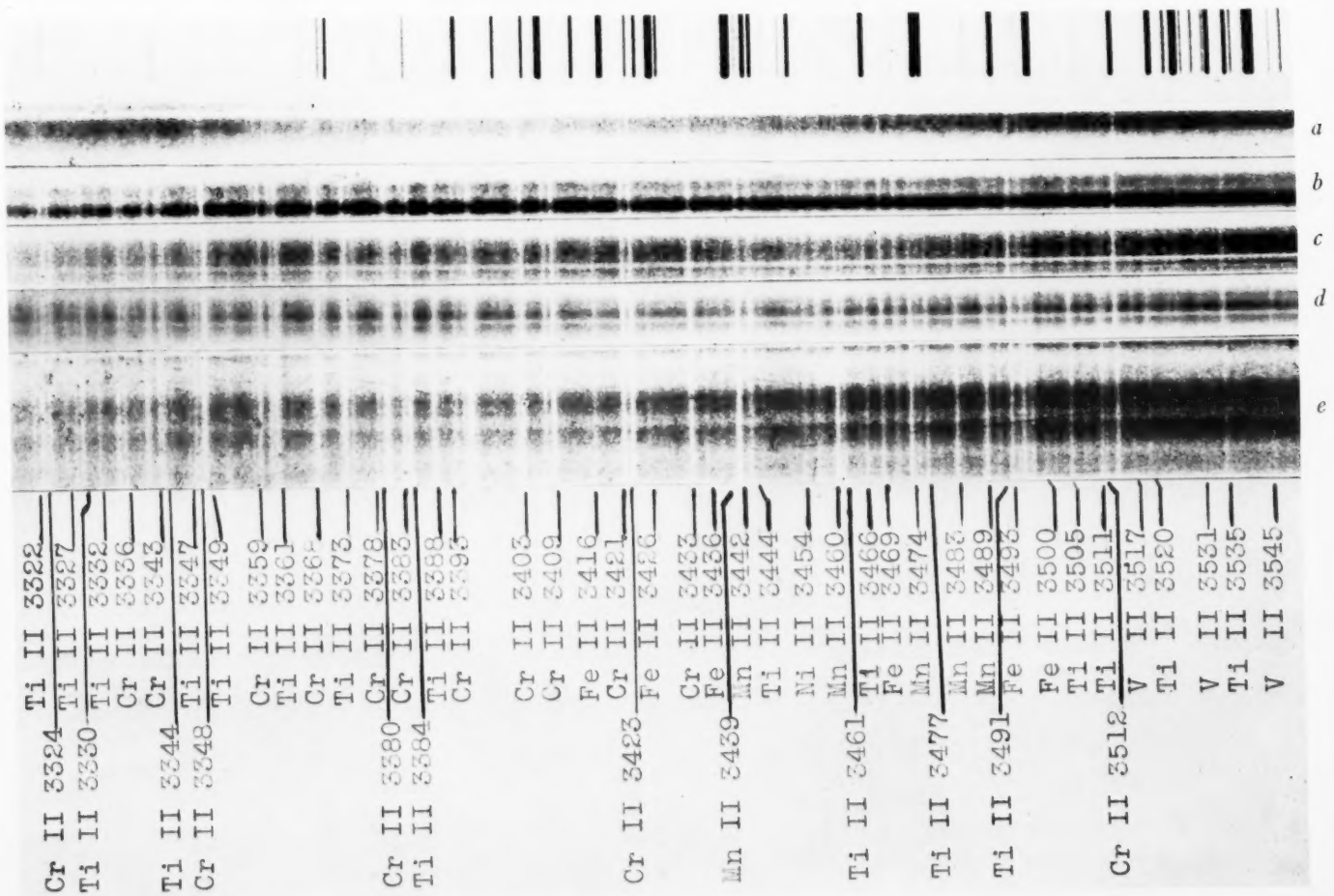
1. Since 1938 the spectrum of Pleione (BS 1180 = 28 Tauri; $\alpha = 3^h43^m2$, $\delta = +23°50'$ [1900]) has shown double bright lines at $H\alpha$ and $H\beta$ and a set of strong, sharp absorption lines resembling the lines of α Cygni.[1] The lines of *Mg* II and *Si* II are conspicuously weak and broad, suggesting that the sharp-line absorption takes place in a layer in which the exciting radiation of the star is diluted by a factor of the order of $W = 0.1$. The very broad *He* I lines of the original star are not now visible, and this may in part be due to continuous absorption within the shell. The violet component of the double emission line at $H\beta$ is somewhat stronger than the red, but on some recent plates the difference is less noticeable than on plates taken in 1938 and 1940.

2. Several stars with shell spectra are known to have variable radial velocities (φ Per, ζ Tau, 17 Lep, 48 Lib). Table 1 gives the velocities measured on 76 spectrograms of Pleione taken at the Yerkes and McDonald Observatories. There are conspicuous fluctuations with a range of about 10 km/sec and a period of about four months. Some of the plates taken in 1941–42 were not intended for accurate determinations of radial velocities, and the observed scatter is large. In 1942–43 the scatter is much less, and the curve is very clearly defined. In Figures 1 and 3 the velocities are plotted separately for each date. Average values are plotted when there were two or more plates during the same night. Figures 2 and 4 show the smoothed curves, obtained by taking running means of three successive velocities, as listed in Table 1.

Two well-defined minima were observed: JD 2430260 and JD 2430685. The difference of 425 days suggests periods of either 106 days or 142 days. The latter value is the more probable one, but the shapes of the two curves are not very similar, and it is possible that the fluctuations in velocity are somewhat irregular. It is interesting that the value $P = 142$ days is similar to the periods of φ Per, ζ Tau, and 17 Lep. In spite of the many differences observed in the spectra of these stars, there appears to be a tendency in all four to show fluctuations of radial velocity which repeat themselves every four or five months. Whether this has a bearing upon the origin of the shell is not known. At present we know only that rapid axial rotation in a B-type star is required to produce

* *Contributions from the McDonald Observatory, University of Texas*, No. 70.

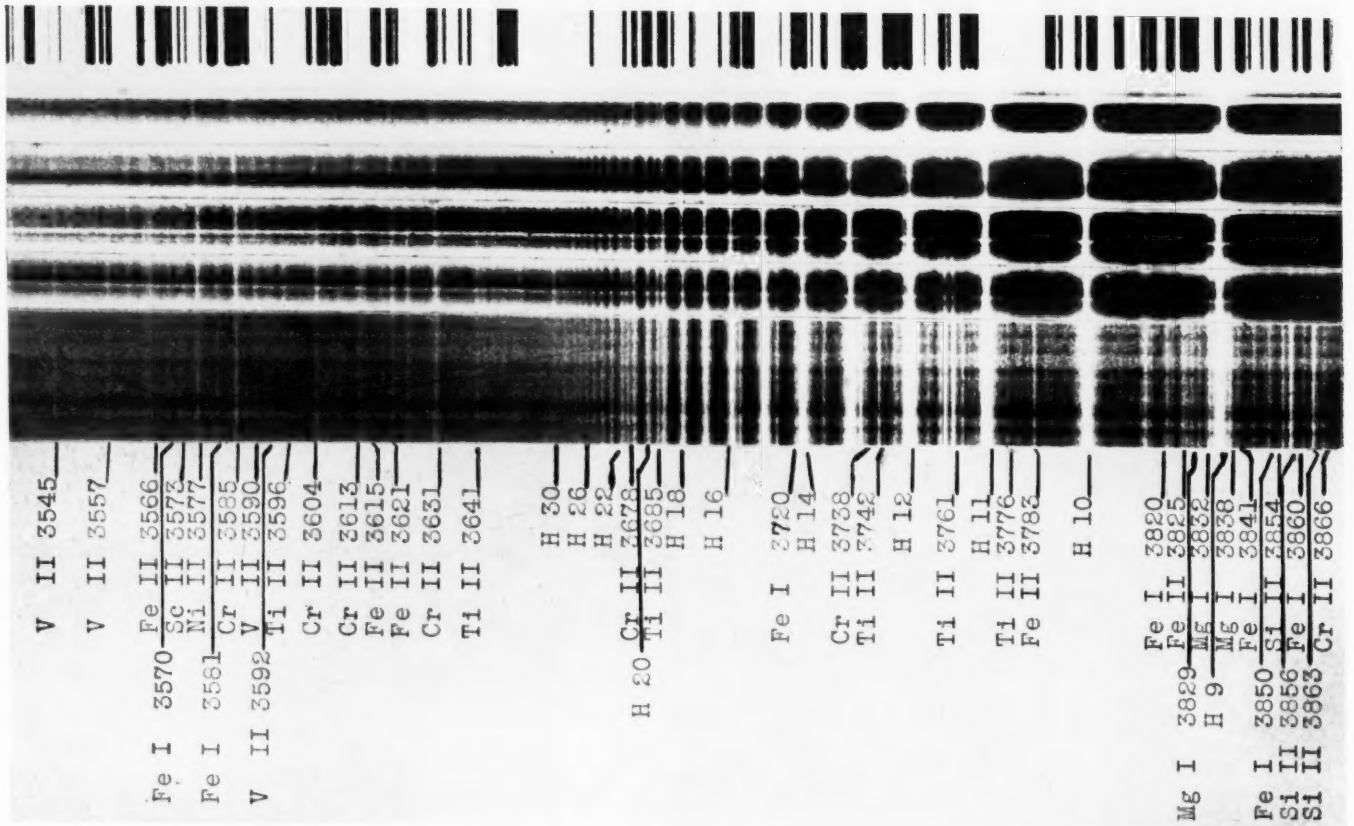
[1] Struve and Swings, *Ap. J.*, **93**, 486, 1941; Kiess, Krogdahl, Bidelman, and Hall, *Pub. A.A.S.*, **10**, 227, 1942.



SPECTRUM OF PLEIONE, REGION λλ 3320–3550

(*a*) Pleione, Nov. 12, 1940; (*b*) Pleione, Nov. 2, 1941; (*c*) Pleione, Jan. 8, 1942; (*d*) Pleione, Nov. 25, 1942; (*e*) α Cygni

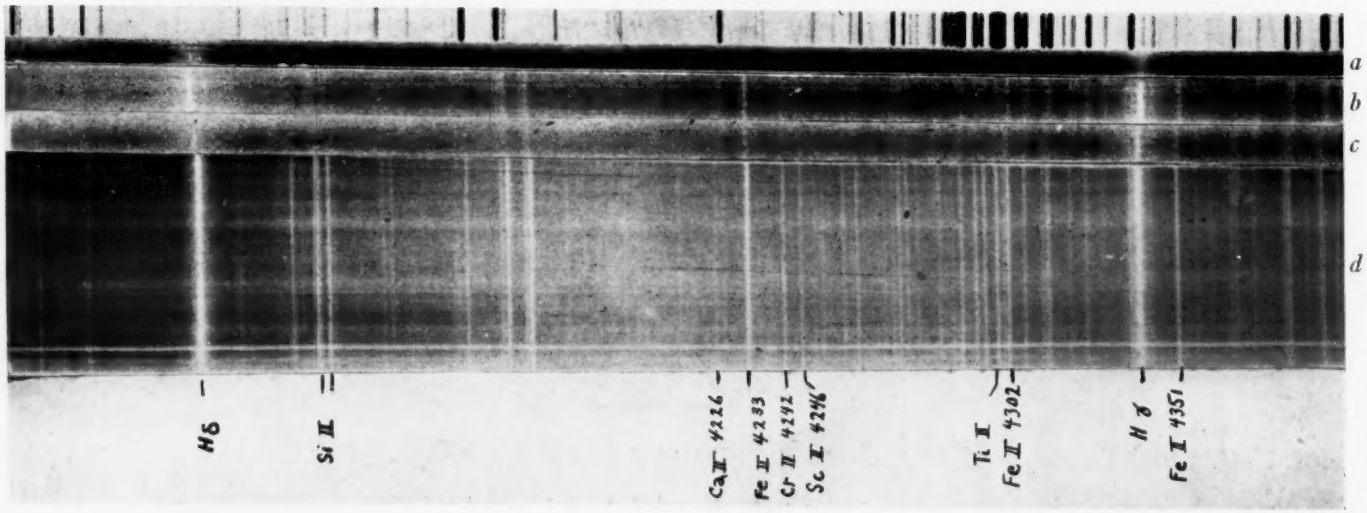
PLATE XXXIV



SPECTRUM OF PLEIONE, REGION λλ 3540–3870

Pleione: (*a*) Nov. 12, 1940; (*b*) Nov. 2, 1941; (*c*) Jan. 8, 1942; (*d*) Nov. 25, 1942; (*e*) α Cygni

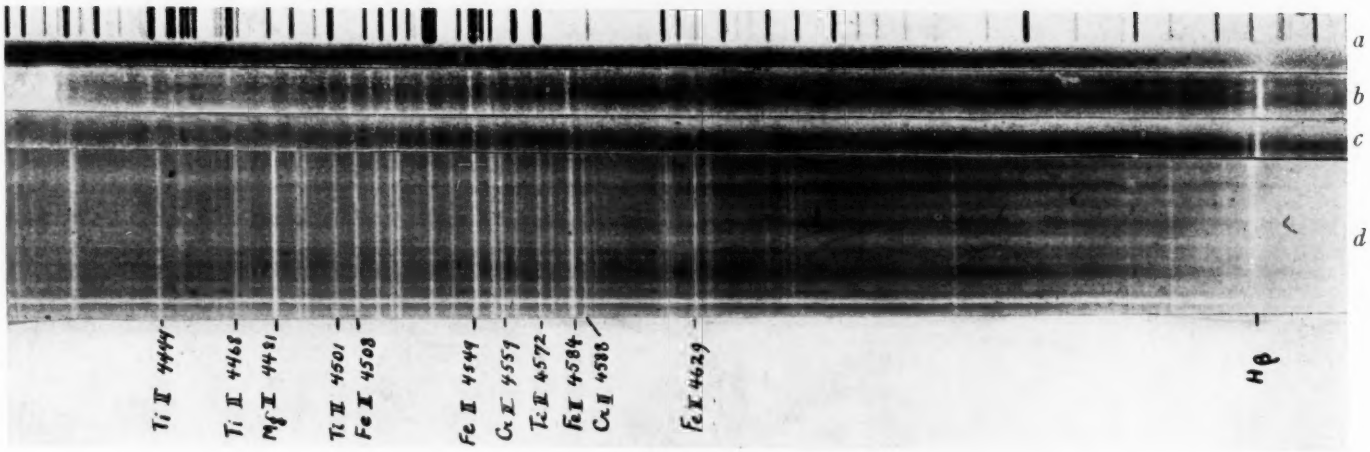
PLATE XXXV



Spectrum of Pleione, Violet Region

(*a*) Pleione, 1906; (*b*) Pleione, Nov. 1941; (*c*) Pleione, 1940; (*d*) α Cygni

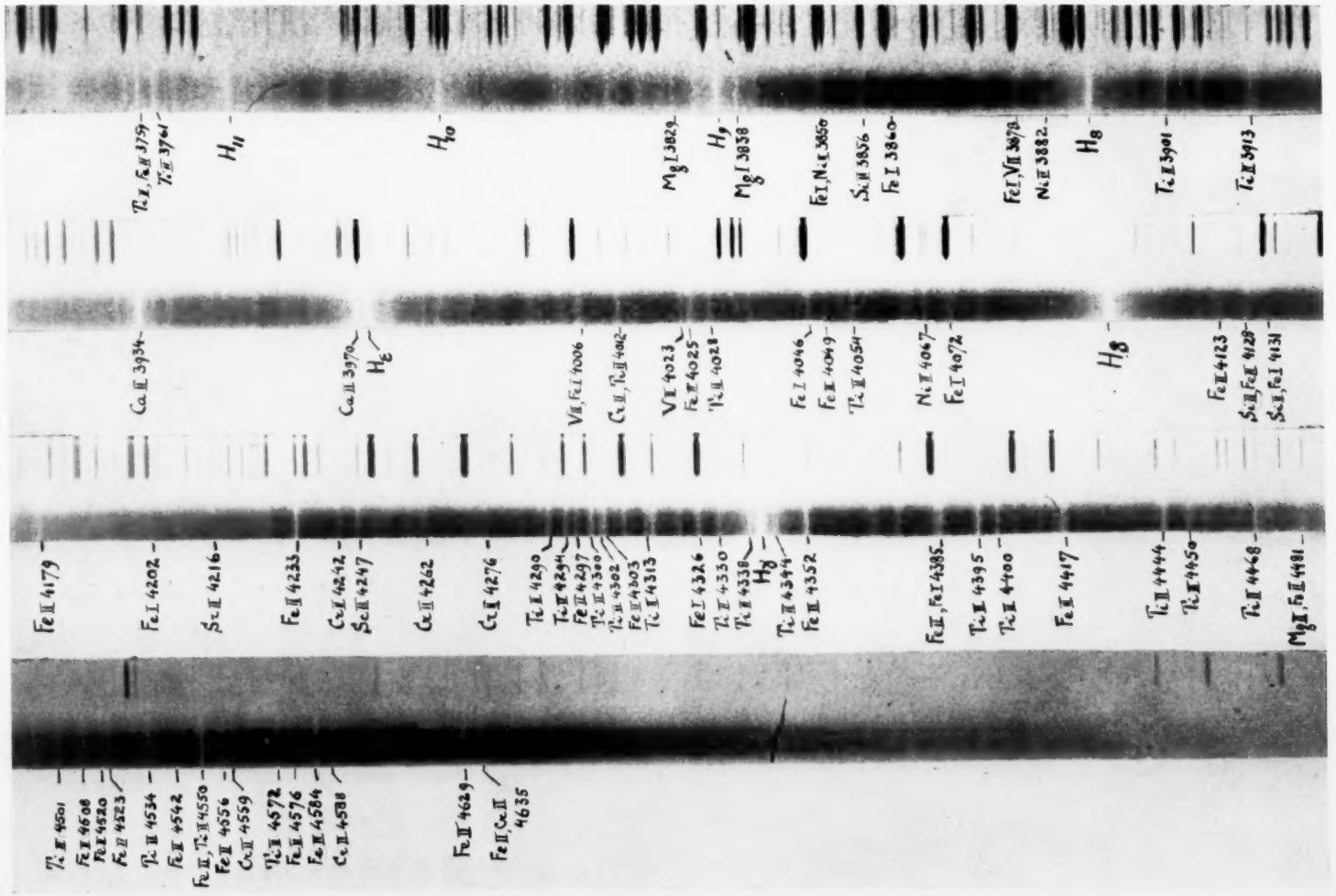
PLATE XXXVI



SPECTRUM OF PLEIONE, BLUE REGION

(*a*) Pleione, 1906; (*b*) Pleione, Nov., 1941, (*c*) Pleione, 1940; (*d*) α Cygni

PLATE XXXVII



SPECTRUM OF PLEIONE, JANUARY 30, 1943, REGION λλ 3750–4700

UNIV. OF MICH.

TABLE 1

RADIAL VELOCITIES OF PLEIONE

Date	U.T.	JD 2429	Velocity (In Km/Sec)	Observatory and Quality
1938 Dec. 16	1h08m	248.55	+ 4.2	Y film
1940 Sept. 13	9 07	885.88	+ 9.1	Y
Nov. 3	11 22	936.97	0.0	Y
Nov. 12	9 45	945.91	+15.4	M
Dec. 8	0 37	971.53	+ 6.3	Y
		JD 2430		
1941 Jan. 7	5 02	001.71	+10.0	M
Aug. 4	10 28	210.94	+ 6.5	M film
Aug. 4	11 04	210.96	+ 7.3	M film
Sept. 4	7 41	241.82	− 1.5	Y poor
Sept. 6	8 10	243.84	− 5.0	Y
Sept. 20	8 15	257.84	+ 1.8	Y
Sept. 26	8 29	263.85	+ 1.2	Y
Sept. 27	8 03	264.84	− 1.4	Y
Oct. 15	9 33	282.90	− 2.3	Y underexposed
Oct. 16	6 33	283.77	+ 1.0	Y
Oct. 24	6 08	291.76	+ 1.8	Y
Oct. 24	10 10	291.92	+ 7.1	Y
Nov. 1	10 57	299.96	+10.2	M
Nov. 1	12 19	300.01	+15.9	M
Nov. 2	8 38	300.86	+ 9.8	M
Nov. 18	6 40	316.78	+11.0	Y poor
Nov. 19	6 32	317.77	+ 7.1	Y
Dec. 11	3 12	339.63	+ 6.8	Y
Dec. 15	2 10	343.59	+ 1.7	Y
1942 Jan. 5	1 40	364.57	+ 6.7	Y
Jan. 8	3 15	367.64	− 3.2	M film, poor
Jan. 8	4 15	367.68	+15.0	M
Jan. 14	2 20	373.60	+ 3.0	Y
Jan. 23	0 12	382.51	− 1.8	Y
Jan. 24	0 30	383.52	+ 2.3	Y
Jan. 27	7 28	386.81	+ 2.6	M
Jan. 31	3 53	390.66	+13.1	M film, poor
Feb. 8	0 44	398.53	+ 7.3	Y
Feb. 20	1 25	410.56	+ 4.9	Y
Apr. 13	1 43	462.57	− 3.6	Y
Aug. 25	8 52	596.87	+ 7.8	Y
Sept. 16	6 50	618.78	+ 8.3	Y
Sept. 17	8 33	619.86	+ 9.8	Y
Sept. 25	8 09	627.84	+13.0	Y
Sept. 27	7 18	629.80	+ 7.9	Y
Sept. 28	7 54	630.83	+ 4.8	Y
Oct. 6	8 07	638.84	+ 7.7	Y
Oct. 6	9 27	638.89	+10.8	Y
Oct. 7	8 07	639.84	+ 8.7	Y
Oct. 7	9 32	639.90	+ 5.8	Y
Oct. 8	7 08	640.80	+ 4.8	Y
Oct. 8	8 16	640.84	+ 8.6	Y
Oct. 17	9 39	649.90	+ 7.5	Y
Oct. 18	6 35	650.77	+ 5.3	Y
Nov. 6	5 51	669.74	− 4.0	Y
Nov. 13	5 35	676.73	+ 1.1	Y
Nov. 18	5 18	681.72	− 3.1	Y
Nov. 25	5 32	688.73	− 5.6	M
Nov. 27	6 10	690.76	− 0.5	Y

TABLE 1—*Continued*

Date	U.T.	JD 2430	Velocity (In Km/Sec)	Plate and Quality
Dec. 4	5^h31^m	697.73	+ 2.2	Y
Dec. 5	5 46	698.74	+ 1.1	Y
Dec. 11	4 39	704.69	+ 3.9	Y
Dec. 16	5 27	709.73	+ 4.8	Y
Dec. 25	3 29	718.64	+ 5.6	Y
Dec. 25	4 22	718.68	+ 4.8	Y
1943 Jan. 11	6 30	735.77	+ 9.8	M
Jan. 20	2 29	744.60	+ 9.7	M
Jan. 20	4 45	744.70	+ 7.1	M film
Jan. 26	5 32	750.73	+ 6.7	M
Jan. 28	2 39	752.61	+10.4	M
Jan. 28	2 42	752.61	+ 7.1	M
Jan. 29	0 31	753.52	+ 2.9	Y
Jan. 29	1 06	753.55	+ 8.1	M
Jan. 29	1 08	753.55	+ 8.0	M
Jan. 30	3 54	754.66	+ 7.1	M film
Feb. 5	2 00	760.58	+ 9.3	Y
Feb. 16	0 21	771.51	+ 9.4	Y
Feb. 16	1 14	771.55	+ 4.1	Y
Feb. 18	1 07	773.55	+ 8.7	Y
Feb. 18	1 39	773.57	+ 5.4	Y
Feb. 23	0 19	778.51	+12.0	Y

a shell spectrum; but, since not all rapidly rotating B stars have shells, it may be concluded that rapid rotation, though necessary, is not sufficient to produce shell absorption. The fluctuations in radial velocity may provide a clue to a further condition which is required and which, when combined with rapid rotation, would constitute a sufficient condition for the origin of a shell.[2]

The average velocity from all 76 plates of Pleione is

$$v_{av} = +5.5 \text{ km/sec} .$$

The radial velocity of the entire cluster of the Pleiades has not been accurately determined. The few published values lead to an average velocity of +7 or +8 km/sec, but most of them are based upon measurements of broad lines in the bright B-type stars. Until the velocity of the cluster has been accurately determined, it will not be possible to state whether the shell of Pleione is stationary or has a very small velocity of expansion.

3. The sharp absorption lines of Pleione have gradually become stronger, and there is as yet no indication that this process has been arrested. Two of our best spectrograms were measured completely: the Process plate, taken with the quartz spectrograph at McDonald on November 25, 1942, was used in the ultraviolet region and as far to the blue as λ 3750. The Process film, taken with the glass prisms at McDonald on January 30, 1943, gave the wave lengths longer than λ 3750. The two dispersions were 40 A/mm and 20 A/mm at λ 3933, respectively. The Process plate had somewhat better contrast than the Process film.

The spectrum of Pleione greatly resembles that of α Cygni. In the ultraviolet region the intensities of the sharp lines are even somewhat greater than in α Cygni. But the dilution effects are as conspicuous as they were in 1940.[1] Plates I, II, III, IV, and V illustrate the development of the shell spectrum. In the early stages *Ni* II was very

[2] These ideas are elaborated upon in a paper by O. Struve, *Pop. Astr.* (in press).

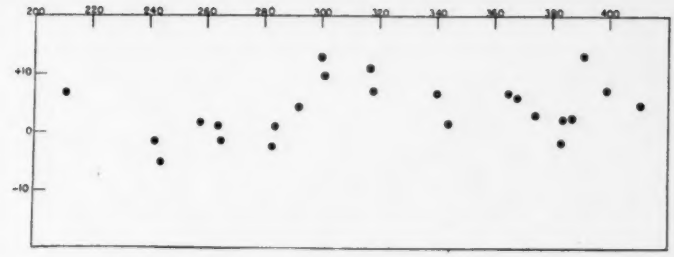


FIG. 1.—Radial velocities of Pleione in 1941–1942

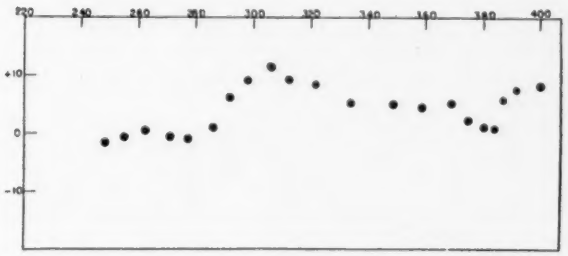


FIG. 2.—Smoothed radial velocities of Pleione in 1941–1942

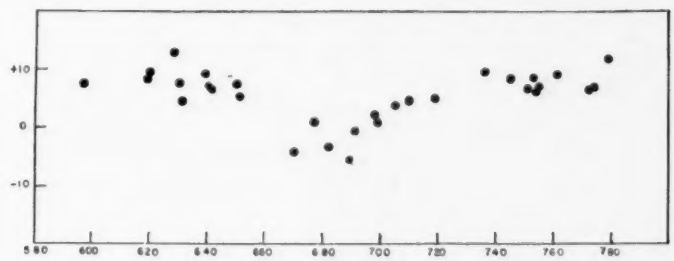


FIG. 3.—Radial velocities of Pleione in 1942–1943

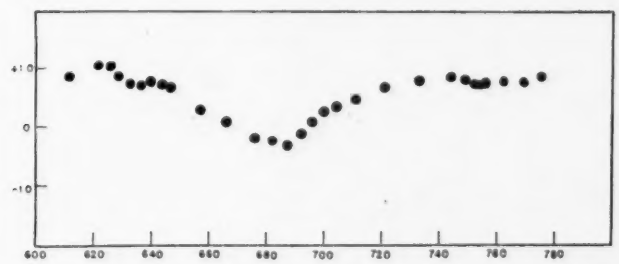


FIG. 4.—Smoothed radial velocities of Pleione in 1942–1943

TABLE 2

LIST OF LINES IN THE SPECTRUM OF PLEIONE IN 1042–43

Wave Length	Int.	Identification*
3307.07	2	*Cr* II 07.04(50), *Cr* II 06.95(50)
3309.06	2	*Ti* II 08.81(100)
3310.70	1	*Cr* II 10.65(35)
3312.26	3	*Cr* II 12.18(40), *Cr* II 11.93(40)
3314.09	1	*Fe* II 14.00(1), *Cr* II 14.57(35), *Cr* II 14.06(18)
3315.52	1	*Ti* II 15.32(100), *Cr* II 15.29(12)
3318.19	1	*Ti* II 18.03(125)
3319.68	0	(α Cygni)
3321.81	1	*Ti* II 21.70(125), (*Fe* II 21.49(1)), (*V* II 21.54(150))
3323.19	5	*Fe* II 23.07(8), *Ti* II 22.94(300), (*Cr* II 23.53(8))
3324.29	4	*Cr* II 24.35(50), *Cr* II 24.06(25), *Cr* II 24.10(20)
3326.89	1	*Ti* II 26.76(125)
3328.31	1	*Cr* II 28.35(20)
3329.55	3	*Ti* II 29.46(200), (*Cr* II 29.45(4)), (*Fe* II 29.07(2))
3332.18	4	*Ti* II 32.11(125)
3335.35	4	*Cr* II 35.28(40), *Ti* II 35.19(150), *Cr* II 35.46(30)
3336.49	3	*Cr* II 36.33(40), (*Fe* II 36.34(pred.))
3337.85	1n	*V* II 37.84(200), *Ti* II 37.85(60), (*Fe* II 38.52(3))
3340.17	7	*Cr* II 39.80(50), *Ti* II 40.34(100), *Cr* II 39.90(20)
3342.32	8	*Cr* II 42.51(50), *Ti* II 41.87(300)
3343.78	1	*Ti* II 43.77(70)
3345.17	0n	*Zr* II 44.80(15)
3346.81	1	*Ti* II 46.73(60)
3347.99	2	*Cr* II 47.84(40)
3349.35	5	*Ti* II 49.41(400), *Ti* II 49.03(800), (*Cr* II 49.34(16)), (*Ti* II 48.84(12))
3350.42	1	*Ni* II 50.42(5), (*Ca* I 50.36(15)), (*Ti* II 50.52(5)), (*Fe* II 50.34(pred.))
3352.14	0	*Ti* II 52.07(15), (*Fe* II 52.40(pred.))
3353.41	2n	*Cr* II 53.12(20), *Sc* II 53.74(60)
3356.01	0	*Fe* II 56.26(m), *Zr* II 56.08(18)
3357.47	1	*Cr* II 57.40(40), *Zr* II 57.26(15), *Fe* II 57.96(0)
3358.57	3	*Cr* II 58.50(75), *Fe* II 58.25(3), (*Fe* II 58.78(pred.))
3360.20	3	*Fe* II 60.10(3), *Cr* II 60.29(100), (*Fe* II 60.31(0)), (*Ti* II 60.12(pred.))
3361.50	5	*Ti* II 61.21(600), *Cr* II 61.77(30), (*V* II 61.51(60))
3363.45	1b	*Cr* II 63.71(12)
3364.40	1b	*Fe* II 65.41(1), *Fe* II 64.22(pred.), (*Cr* II 64.72(1))
3366.38	1n	*Ti* II 66.18(50), *Fe* II 66.96(3)
3367.93	5	*Cr* II 68.05(150)
3369.23	3	*Fe* II 69.35(3), *Cr* II 69.05(18), *Ti* II 69.21(25), (*Sc* II 68.95(20))
3371.06	0	*Fe* I 70.79(300), *Co* II 70.94(50), (*Cr* II 71.46(1)), (*Cr* II 70.71(0))
3372.80	3	*Ti* II 72.80(400)
3374.27	1n	*Ti* II 74.35(30), *Ni* II 73.98(4), *Zr* II 74.71(15)
3376.81	0	*Cr* II 76.72(5), (*Cr* II 76.27(10))
3378.33	2	*Cr* II 78.34(25)
3380.01	10n	*Cr* II 79.82(60), *Cr* II 79.37(30), *Ti* II 80.28(150)
3381.12	1	*Fe* II 81.00(4), (*Fe* II 81.36(pred.)), (*La* II 80.89(250))
3382.64	3	*Cr* II 82.68(60)
3383.85	4	*Ti* II 83.76(300)
3387.87	4	*Ti* II 87.84(125), *Fe* II 88.13(2), *Co* II 87.72(60), (*Cr* II 87.73(5))
3388.90	1	*Ti* II 88.75(35)
3391.41	2	*Fe* II 91.30(1), *Cr* II 91.43(35)

* Certain *Cr* II lines of laboratory intensity 0, 1, 2, 3, have been written between parentheses; they correspond to a slightly different intensity scale and are actually stronger than would appear from their intensities.

TABLE 2—*Continued*

Wave Length	Int.	Identification*
3392.99	1	*Cr* II 93.00(35)
3394.33	6	*Cr* II 94.32(35), *Ti* II 94.57(200)
3397.85	0n	*Fe* II 98.35(4), *Ni* II 97.82(1)
3399.73	1n	*Cr* II 99.54(18), (*Zr* II 99.36(10)), (*Cr* II 00.08(2))
3402.46	1	*Ti* II 02.42(90), *Cr* II 02.43(25)
3403.29	4	*Cr* II 03.32(100)
3405.05	1n	*Zr* II 04.84(12), (*V* II 04.43(80)), (*Cr* II 05.3(1n))
3407.22	3n	*Ni* II 07.30(8), *Ti* II 07.20(50)
3408.73	4	*Cr* II 08.76(150)
3415.82	2	*Fe* II 16.02(5), (*Co* II 15.78(75))
3418.72	0	(*Fe* I 18.51(150))
3421.12	5	*Cr* II 21.20(75)
3422.64	5	*Cr* II 22.74(125), (*Ti* II 22.66(10))
3424.22	0	(*Co* II 23.85(75)), (*Cr* II 24.65(1))
3425.59	1	*Fe* II 25.58(3)
3428.27	0nn	*Cr* II 28.94(7), (*Cr* II 27.92(1)), (*Fe* II 28.64(pred.))
3430.37	0nn	*Zr* II 30.53(30), *Cr* II 30.42(3), (*Fe* II 30.15(pred.))
3433.31	6	*Cr* II 33.30(75)
3436.03	1	*Fe* II 36.11(5)
3437.85	0n	*Zr* II 38.23(100), (*Cr* II 37.93(2))
3439.07	1	*Mn* II 38.98(20)
3440.82	1	*Fe* I 40.61(500), (*Cr* II 40.60(1))
3441.94	4	*Mn* II 41.98(100), (*Fe* II 42.24(3)), (*Fe* II 41.90(0))
3444.26	4	*Ti* II 44.31(150), (*Cr* II 44.34(4))
3446.12	1	*Co* II 46.40(100)
3448.01	0	*Fe* II 48.43(1)
3449.46	1	(*Cr* II 49.28(2))
3451.12	1	*Fe* II 51.23(2), *Fe* II 51.32(2), (*Fe* II 51.61(2))
3452.37	1	*Ti* II 52.47(100)
3453.95	2	*Ni* II 54.16(5), *Fe* II 53.59(2)
3454.66	1	*Cr* II 54.98(35)
3456.81	2nn	*Fe* II 56.93(5), *Ti* II 56.39(125), *Cr* II 57.62(30), *V* II 57.15(300)
3460.27	4	*Mn* II 60.31(75), (*Mn* II 60.04(8)), (*Cr* II 59.29(25)), (*Cr* II 60.03(1))
3461.41	3	*Ti* II 61.50(125)
3464.19	1	*Fe* II 63.97(1), *Fe* II 64.50(3), *Mn* II 64.04(7), (*Sr* II 64.47(50)), (*Cr* II 64.02(4))
3465.58	3	*Ti* II 65.56(60), (*Ni* II 65.62(1))
3468.66	4	*Fe* II 68.68(8)
3471.38	3n	*Cr* II 72.07(25), *Ni* II 71.35(2), *Fe* II 70.24(1)
3473.98	3	*Mn* II 74.04(50), *Mn* II 74.12(40), *Fe* II 73.82(2)
3475.61	1	*Cr* II 75.13(20), *Fe* II 75.74(pred.), *Fe* II 75.25(pred.)
3477.16	3	*Ti* II 77.18(100), (*Ti* II 76.98(8))
3479.71	1	*Fe* II 79.91(2), (*Zr* II 79.39(30)), (*V* II 79.84(80))
3481.04	0	*Ti* II 80.90(25), *Zr* II 81.14(35)
3482.82	3	*Mn* II 82.90(40), (*Cr* II 82.58(12))
3484.10	1	*Fe* II 84.35(1), *Cr* II 84.15(20)
3486.31	1	*V* II 85.92(250)
3487.95	0b	*Fe* II 87.99(3), *Ca* I 87.60(100)
3488.61	2b	*Mn* II 88.68(40), (*Cr* II 89.07(2))
3490.92	3	*Ti* II 91.05(70), *Fe* I 90.57(400)
3493.30	5	*Fe* II 93.47(10), (*V* II 93.16(150))
3494.69	0	*Fe* II 94.67(5), (*Cr* II 94.52(4))
3495.78	3	*Mn* II 95.83(40), *Fe* II 95.62(4), *Cr* II 95.56(20) (*Cr* II 95.37(25)), (*Y* II 96.09(80))
3497.49	3	*Mn* II 97.54(25), *Mn* II 96.81(20), *Fe* II 97.81(m), *V* II 97.03(200), (*Fe* II 97.73(pred.))
3500.03	2	*Fe* II 99.88(4), *Ti* II 00.34(35)

TABLE 2—*Continued*

Wave Length	Int.	Identification*
3501.76	2	*Co* II 01.73(200), (*Cr* II 01.53(1))
3503.32	1	*Fe* II 03.47(2), (*Fe* II 03.07(0))
3504.82	5	*Ti* II 04.89(150), (*V* II 04.43(400))
3507.43	2n	*Fe* II 07.39(3), (*Fe* II 08.21(1))
3510.60	3	*Ti* II 10.84(125)
3511.73	2	*Cr* II 11.84(35)
3513.95	4	*Ni* II 13.93(8), *Fe* I 13.82(400)
3515.68	1	*Fe* II 15.82(12), (*Cr* II 15.37(1))
3517.02	2	*V* II 17.30(800)
3518.90	0	(*Cr* II 18.62(3))
3520.32	2	*Ti* II 20.25(18), (*V* II 20.02(120))
3521.47	1	*Fe* I 21.26(300), (*V* II 21.84(90))
3523.68	1	
3524.70	1	*V* II 24.71(200), *Ti* II 24.87(5), (*Ni* I 24.54(1000))
3526.40	1n	*Fe* I 26.04(80), *Fe* I 26.17(50), *Fe* I 26.68(80)
3528.04	0	(*Cr* II 28.26(1))
3530.38	1n	*V* II 30.76(500), (*Cr* II 30.72(1)), (*Cr* II 30.05(1))
3533.53	1	*Ti* II 33.87(35), (*Fe* II 33.19(pred.))
3535.47	4	*Ti* II 35.41(125), *Fe* II 35.63(2), (*Sc* II 35.73(30)), (*Mg* II 35.04(8)), (*Cr* II 35.50(1))
3538.61	1	*Mg* II 38.86(6), (*Cr* II 38.47(1))
3541.59	0	(*Fe* I 42.08(150)), (*Fe* I 41.09(200)), (*V* II 41.34(50))
3545.13	2	*V* II 45.19(1000), (*Co* II 45.03(25))
3547.88	1	
3549.17	1	*Fe* II 49.03(1), *V* II 49.01(100), *Ti* II 49.27(pred.)
3552.10	0n	*Zr* II 51.94(18), *Cr* II 52.42(2)
3556.89	2	*V* II 56.80(1500), (*Zr* II 56.61(30))
3558.39	1	*Fe* I 58.52(400), *Sc* II 58.54(40)
3561.26	2n	*Ti* II 61.57(20), (*Cr* II 60.91(1))
3564.73	1n	(*Cr* II 65.31(5)), (*Cr* II 64.31(1))
3566.15	2	*Fe* II 66.15(3), *Fe* II 66.05(2), *Ti* II 65.99(25), *V* II 66.18(200)
3567.78	1	*Sc* II 67.70(40)
3570.25	1	*Fe* I 70.10(300)
3572.66	1	*Sc* II 72.52(50), (*Zr* II 72.47(30))
3573.98	1	*Ti* II 73.74(40)
3576.63	5	*Ni* II 76.76(3), (*Sc* II 76.34(45)), (*Zr* II 76.88(20))
3578.98	0n	*Cr* I 78.69(500), *Ti* II 78.69(5)
3581.14	3	*Fe* I 81.19(1000), (*Sc* II 80.93(40))
3582.18	1n	
3585.37	8	*Cr* II 85.31(60), *Cr* II 85.54(40)
3587.50	1	*Ti* II 87.13(25), *Al* II 87.44(80)
3589.69	3n	*V* II 89.74(1000), (*Sc* II 89.63(12))
3592.06	1	*V* II 92.01(800)
3593.35	1	*V* II 93.32(600), *Ti* II 93.09(30), *Cr* I 93.49(500)
3595.94	4	*Ti* II 96.05(125)
3597.67	0	*Ni* I 97.70(1000), (*Cr* II 97.55(1))
3601.74	0n	(*Y* II 01.92(100))
3603.72	5	*Cr* II 03.80(40), *Cr* II 03.86(20), *Cr* II 03.61(20)
3605.77	1n	*Fe* I 05.46(300), *Cr* I 05.33(500)
3607.40	1	(*Cr* II 07.32(1))
3608.86	2	*Fe* I 08.86(500), (*Ni* II 08.7(pred.)), (*Cr* II 08.66(3))
3610.38	0nn	*Ni* I 10.46(1000), *Fe* II 10.33(pred.), (*Fe* I 10.16(100))
3613.59	3	*Cr* II 13.26(15), *Cr* II 13.21(20), *Sc* II 13.84(70), (*Ti* II 13.33(pred.))
3614.91	2	*Fe* II 14.87(5), (*Zr* II 14.79(18))
3618.99	3	*Fe* I 18.77(400), *V* II 18.92(200)
3621.25	4	*Fe* II 21.27(6), *V* II 21.20(150), (*Co* II 21.22(100))
3624.77	4	*Ti* II 24.83(125), *Fe* II 24.89(5), *Fe* II 24.69(2)

TABLE 2—*Continued*

Wave Length	Int.	Identification*
3625.67	1	*V* II 25.61(50)
3627.37	0	*Fe* II 27.17(1), *V* II 27.71(60), *Ti* II 27.71(12)
3628.98	0	*Y* II 28.71(100)
3631.44	8	*Cr* II 31.49(50), *Cr* II 31.72(40), *Fe* I 31.46(500)
3635.27	0n	(*Ti* II 35.64(pred.))
3637.90	0	(*Fe* I 38.30(100))
3641.18	3	*Ti* II 41.33(150)
3642.86	1	*Sc* II 42.78(50), *Cr* II 43.22(10)
3645.41	1	*Sc* II 45.31(50), *Fe* II 45.78(pred.), (*La* II 45.41(200))
3647.70	1	*Fe* I 47.84(500), (*Cr* II 47.40(8))
3649.25	0	*Fe* I 49.51(100), (?*Cr* II 49.66(2)), (?*Cr* II 49.20(1))
3650.54	0	*Cr* II 50.37(40)
3651.78	1	*Cr* II 51.68(12), *Sc* II 51.80(85)
3658.05	1	*Cr* II 58.19(20)
3659.73	3	*Ti* II 59.76(150)
3661.20	1	*H* 31 61.22(. . .)
3662.14	1	*H* 30 62.26(. . .), *Ti* II 62.24(100)
3663.24	1	*H* 29 63.40(. . .)
3664.80	2	*H* 28 64.70(. . .), *Cr* II 64.95(30)
3666.06	3	*H* 27 66.10(. . .)
3667.69	3	*H* 26 67.68(. . .)
3669.49	4	*H* 25 69.47(. . .), (*V* II 69.41(300))
3671.44	4	*H* 24 71.48(. . .)
3673.75	4	*H* 23 73.76(. . .)
3676.34	5	*H* 22 76.36(. . .)
3677.73	4	*Cr* II 77.69(40), *Cr* II 77.86(50), *Cr* II 77.93(30)
3679.35	5	*H* 21 79.35(. . .)
3682.72	6	*H* 20 82.81(. . .)
3685.19	5	*Ti* II 85.19(700), (*Cr* II 84.25(25))
3686.79	7	*H* 19 86.83(. . .), (*Cr* II 86.67(20))
3691.53	10	*H* 18 91.56(2)
3694.42	1n	*Fe* I 94.01(400), *Fe* I 95.05(200)
3697.14	15	*H* 17 97.15(3), (*Cr* II 98.00(35))
3699.82	1n	
3700.89	1n	*Fe* I 01.09(300), (*Cr* II 00.73(1))
3703.85	15	*H* 16 03.86(4)
3705.99	3n	*Ca* II 06.03(40), *Ti* II 06.23(125)
3707.69	1	(*Fe* I 07.82(80)), (*Fe* I 07.92(80)), (*Mn* II 08.06(1))
3709.35	1n	*Fe* I 09.25(600), *Zr* II 09.27(60), (*V* II 09.33(40)), (*Mn* II 09.88(1))
3711.93	10	*H* 15 11.98(5)
3712.62	3	*Cr* II 12.97(35)
3715.28	5	*V* II 15.48(1200), *Cr* II 15.19(20), *Cr* II 15.45(20)
3718.54	0	(*V* II 18.16(60)), (*Fe* I 18.41(80))
3720.09	2	*Fe* I 19.93(1000), (*Cr* II 19.72(1))
3721.97	18	*H* 14 21.95(6), (*Ti* II 21.64(125))
3723.69	1	*Cr* II 23.40(15), *Ti* II 23.63(15), *Ti* II 24.11(18)
3725.12	1	*Fe* II 25.30(3)
3727.40	3n	*Cr* II 27.37(40), *V* II 27.35(1000), *Fe* II 27.04(m), *Fe* I 27.62(200), (*Zr* II 27.72(10))
3732.70	0n	*V* II 32.76(800), *Fe* I 33.32(400), *Fe* I 32.40(200)
3734.47	20	*H* 13 34.37(8), (*Fe* I 34.87(1000))
3736.95	3n	*Ca* II 36.90(50), *Fe* I 37.13(1000), (*Cr* II 37.55(10))
3738.11	1n	*Cr* II 38.38(25)
3741.62	4	*Ti* II 41.64(200)
3743.16	1	*Fe* I 43.36(200)
3745.83	3	*V* II 45.81(800), *Fe* I 45.56(500), (*Zr* II 45.97(40))
3748.56	5	*Fe* II 48.49(8), *Fe* I 48.26(500), (*Cr* II 48.68(7)), (*Ti* II 48.00(25))

TABLE 2—*Continued*

Wave Length	Int.	Identification*
3750.16	13	*H* 12 50.15(10)
3754.36	2n	*Cr* II 54.59(20), *Fe* II 55.56(4), *Fe* I 53.61(150)
3757.73	3	*Ti* II 57.69(100), *Fe* I 58.23(700)
3759.32	5	*Ti* II 59.29(400), *Fe* II 59.46(6)
3761.40	6	*Ti* II 61.32(300)
3761.89	0	*Ti* II 61.89(15), *Cr* II 61.90(8), *Cr* II 61.69(7)
3762.91	0	*Fe* II 62.89(5)
3763.88	1	*Fe* I 63.79(500), *Fe* II 64.09(pred.)
3765.60	1	*Cr* II 65.62(8), (*Cr* II 65.28(3))
3767.41	2	*Fe* I 67.19(500)
3769.59	2	*Ni* II 69.45(5)
3770.65	15	*H* II 70.63(15), (*V* II 70.97(400))
3774.28	1	*Y* II 74.34(300)
3776.06	2	*Ti* II 76.06(60)
3778.32	1	*V* II 78.36(100), *Cr* II 78.69(6), (*Fe* II 78.37(pred.))
3779.40	0	*Fe* I 79.45(100), (*Cr* II 79.06(1))
3781.39	1	*Fe* II 81.51(1)
3783.28	2n	*Fe* II 83.35(4), (*Cr* II 83.56(2))
3786.48	1n	(*Fe* I 86.68(125)), (*Fe* I 86.18(100)), (*Ti* II 86.33(pred.))
3787.57	1	*Fe* I 87.88(500), *V* II 87.23(150)
3788.62	1	*Y* II 88.70(200)
3794.72	1n	*Fe* I 95.00(500), *La* II 94.77(500), (*V* II 94.37(50)), (*Cr* II 95.06(1?))
3797.92	15	*H* 10 97.91(20)
3813.35	1	*Ti* II 13.39(20), *Fe* I 12.96(400)
3814.50	2n	*Fe* II 14.12(4), *Ti* II 14.59(35), *Cr* II 14.00(12)
3815.55	1n	*Fe* I 15.84(700), *V* II 15.38(200), (*Cr* II 15.77(2))
3818.47	0n	*Y* II 18.35(60)
3820.58	2n	*Fe* I 20.43(800), (*Cr* II 20.48(2))
3824.84	2n	*Fe* II 24.91(4)
3825.84	1	*Fe* I 25.88(500)
3827.41	1n	*Fe* II 27.08(4), *Fe* I 27.82(200)
3829.27	2	*Mg* I 29.35(100), (*Fe* II 28.86(?2))
3832.69	3n	*Mg* I 32.31(250), *Fe* II 32.96(?2), (*Cr* II 32.74(1)), (*Y* II 32.89(100))
3835.39	10	*H* 9 35.40(40)
3838.15	3	*Mg* I 38.26(300), *Fe* II 38.04(?2)
3840.74	2n	*Fe* I 40.44(400), *Fe* I 41.05(500)
3843.02	1	*Sc* II 43.00(20), *Zr* II 43.03(30), *Mn* II 42.98(1), (*Cr* II 42.66(1))
3844.56	1	.....
3845.17	1	*Fe* II 45.18(m), (*Cr* II 45.16(1))
3847.32	0	*V* II 47.32(100)
3848.60	0	(*Mg* II 48.24(10))
3849.82	2	*Fe* I 49.97(500), *Ni* II 49.58(2)
3851.94	0n	*Fe* I 50.82(200), *Fe* I 52.57(150)
3854.26	0	(*Si* II 53.67(3))
3855.96	2	*Si* II 56.03(8)
3859.83	2n	*Fe* I 59.91(1000)
3861.15	1	*Fe* II 60.91(3), (*Cr* II 61.34(1))
3862.48	1n	*Si* II 62.59(6)
3863.78	1n	*Fe* II 63.95(1), *Fe* II 63.41(1), *V* II 63.81(60)
3865.38	1	*Cr* II 65.59(75), *Fe* I 65.53(600))
3866.69	1n	*V* II 66.74(60), *Cr* II 66.54(7), *Cr* II 66.01(5)
3867.49	0	*Fe* I 67.22(150), (*Cr* II 67.86(1), (*Cr* II 67.80(1))
3871.44	0	*La* II 71.65(200), *Fe* I 71.75(100)
3872.51	2n	*Fe* I 72.50(300), (*Cr* II 72.57(1?)), *Fe* II 72.76(pred.)
3878.34	3n	*Fe* I 78.57(300), *Fe* I 78.02(400), *V* II 78.71(300), (*Y* II 78.30(20))

TABLE 2—*Continued*

Wave Length	Int.	Identification*
3882.16	2	*Ni* II 81.92(1)
3889.12	10	*H* 8 89.05(60)
3892.87	0	(*S* II 92.32(35), (*Cr* II 93.31(1))
3895.92	1	*Fe* I 95.66(400), *V* II 96.15(60)
3899.30	1	*V* II 99.14(200), *Fe* I 99.71(500)
3900.57	4	*Ti* II 00.54(100), *Al* II 00.68(200)
3903.20	2	*V* II 03.27(250), *Fe* I 02.95(500)
3905.96	3	*Fe* II 06.04(5), *Cr* II 05.64(25), *Si* I 05.53(20), *Fe* I 06.48(300)
3907.19	1	(*Cr* II 07.36(1)), (*Sc* I 07.48(125))
3913.50	5	*Ti* II 13.46(70), (*Fe* I 13.63(100))
3914.26	1	*Fe* II 14.48(2), *V* II 14.33(250)
3915.38	0	(*Cr* II 15.58(1))
3916.38	1	*V* II 16.42(200), (*Fe* I 16.73(100)), *La* II 16.07(300)
3919.87	0n	*Fe* I 20.26(500)
3923.03	1	*Fe* I 22.91(600)
3927.95	0	*Fe* I 27.92(500)
3930.38	1	*Fe* I 30.31(600), (*Fe* II 30.31(pred.))
3932.17	0	*Ti* II 32.02(30)
3933.74	10	*Ca* II 33.67(600)
3935.72	1n	*Fe* II 35.94(6)
3938.46	2n	*Fe* II 38.29(2), *Fe* II 38.97(4)
3941.06	0n	*Fe* I 40.82(150)
3943.88	1n	(*Al* I 44.03(2000)), (*Mn* II 43.82(1)), (*Cr* II 43.64(1))
3945.11	1	(*Cr* II 45.11(1)), (*Fe* II 45.21(pred.))
3947.21	1	*O* I 47.33(300), (*Fe* I 47.53(70))
3949.85	0	*Fe* I 49.96(150)
3951.75	1n	*V* II 51.97(500), (*Fe* I 51.17(150))
3956.22	1n	*Fe* I 56.68(150), *Fe* I 56.46(100)
3960.97	1n	*Fe* II 60.89(3), (*Al* I 61.53(3000))
3968.56	8	*Ca* II 68.47(500)
3970.15	15	*H*ε 70.07(80)
3973.73	1n	*Fe* II 74.16(3), *V* II 73.64(300), *Ca* I 73.71(200)
3977.68	0	*Fe* I 77.74(300), *V* II 77.73(60)
3979.59	1	*Cr* II 79.51(20)
3981.87	1	*Fe* I 81.77(150), (*Fe* II 81.61(pred.)), (*Ti* II 82.01(3))
3983.79	0	*Fe* I 83.96(200), (*Cr* I 83.91(200))
3985.86	0	*Mn* II 86.01(1), (*Fe* I 85.39(125)), (*Fe* I 86.17(125)), (*V* II 85.78(30))
3987.33	1	.....
3996.99	1	*V* II 97.13(200), *Fe* I 97.40(300)
3999.03	1	*Zr* II 98.98(30), (*S* II 98.79(60))
4002.61	1n	*Fe* II 02.55(3), *Fe* II 02.07(2), *Cr* II 02.48(5), *Cr* II 03.33(25), *V* II 02.94(80)
4004.35	0	*Fe* II 04.15(pred.)
4005.64	3n	*V* II 05.71(800), *Fe* I 05.25(250)
4008.28	0	(*Fe* II 07.72(pred.))
4012.42	4	*Cr* II 12.50(30), *Ti* II 12.39(50), *Fe* II 12.47(1)
4015.66	1	*Ni* II 15.50(1)
4023.40	1	*V* II 23.39(600), (*Sc* I 23.69(100)
4024.89	4	*Fe* II 24.55(5), *Fe* I 24.74(120), *Ti* II 25.14(25)
4028.34	3	*Ti* II 28.35(80)
4029.73	1	(*Zr* II 29.68(20)), (*Fe* I 29.64(80))
4030.77	0	*Fe* I 30.49(120), *Mn* I 30.75(500), (*Cr* II 30.68(3))
4032.97	0	*Fe* II 32.95(3), *Mn* I 33.07(400)
4035.53	1	*V* II 35.63(400), (?*Cr* II 35.15(1))
4041.23	0	(*Mn* I 41.36(100)), (*Fe* II 41.64(pred.))
4044.11	0	*Fe* II 44.01(m)
4045.79	2	*Fe* I 45.81(400), (*Zr* II 45.63(15))

TABLE 2—*Continued*

Wave Length	Int.	Identification*
4048.73	2	*Fe* II 48.83(3), (*Zr* II 48.68(25)), (*Cr* II 49.14(18))
4051.25	1	*V* II 51.34(100), (*Fe* II 51.21(pred.))
4052.21	0	(*Cr* II 51.97(12))
4053.92	4	*Ti* II 53.84(25), (*V* II 53.59(60)), (*Cr* II 54.11(8))
4055.91	1	(*Cr* II 56.07(4)), (*Ti* II 56.21(2))
4057.43	0	*Fe* II 57.46(2)
4061.84	0	*Fe* II 61.79(1)
4063.28	2n	*Fe* I 63.60(400)
4066.93	3	*Ni* II 67.05(3), (*Fe* I 66.98(100))
4070.87	0	*Cr* II 70.90(10)
4071.51	2	*Fe* I 71.74(300)
4075.51	0	(*Cr* II 75.63(pred.)), (*Si* II 75.45(2))
4077.63	1	*Sr* II 77.71(500), (*La* II 77.35(300)), (*Fe* II 77.16(3))
4081.86	1	(*Cr* II 82.30(10))
4085.51	1	*Fe* I 85.32(100)
4101.79	20	*Hδ* 01.74(100)
4107.19	0	*Fe* I 07.49(120)
4111.10	0	*Cr* II 11.01(18)
4118.96	0n	*Fe* I 18.55(200), (*Co* I 18.77(1000))
4122.51	3	*Fe* II 22.64(4)
4128.10	2n	*Si* II 28.05(8), *Fe* II 28.73(3)
4131.69	2n	*Si* II 30.88(10), *Fe* I 32.06(300), (*Mn* II 32.28(1))
4134.73	1	*Fe* I 34.68(150)
4136.71	1	*Mn* II 36.91(2), (*Fe* I 37.00(100))
4143.67	2n	*Fe* I 43.87(400), *Fe* I 43.42(200)
4145.73	1	*Cr* II 45.77(25), (*S* II 45.10(250))
4147.20	0	(*Fe* I 47.67(200))
4148.86	1	(*Fe* I 49.37(100)), (*Zr* II 49.22(75))
4151.01	0n	*Cr* II 51.00(5), *Zr* II 50.97(10), *N* I 51.46(1000)
4155.81	1	(*Zr* II 56.24(15))
4158.31	0	*Fe* I 57.79(150), *Fe* I 58.80(100)
4161.09	3n	*Ti* II 61.54(30), *Zr* II 61.20(20), *Cr* II 61.05(2), (*Al* II 60.24(12))
4163.65	4	*Ti* II 63.65(150)
4167.92	1	(*Mg* I 67.39(6)), (*Mg* I 67.65(5))
4171.90	4	*Ti* II 71.90(70), (*Cr* II 71.92(3))
4173.43	6	*Fe* II 73.45(8), *Ti* II 73.55(40)
4175.99	0	*Fe* I 75.64(100), *Fe* I 76.57(100)
4177.71	3	*Fe* I 77.60(100), *Fe* II 77.70(pred.), (*Y* II 77.54(125))
4178.93	6	*Fe* II 78.85(8), (*Cr* II 79.43(12))
4181.68	0	*Fe* I 81.76(200), (*Cr* II 81.50(1))
4184.19	0	*Ti* II 84.33(20)
4187.36	0n	*Fe* I 87.04(250), *Fe* I 87.80(200), (*Zr* II 86.70(12))
4195.20	1	*Fe* I 95.34(150), *Cr* II 95.41(10)
4198.60	1	*Fe* I 98.31(250), *Fe* I 99.10(300), (*Si* II 98.25(3))
4202.12	3	*Fe* I 02.03(400), (*V* II 02.35(150))
4204.90	1	*V* II 05.08(250)
4208.28	0n	*Fe* I 08.61(100), *Zr* II 08.99(30)
4211.46	0n	*Fe* I 10.35(300), *Zr* II 11.88(12)
4215.59	2	*Sr* II 15.52(400)
4219.03	1	*Fe* I 19.36(250)
4222.28	0	*Fe* I 22.22(200), (*Cr* II 22.00(1))
4225.32	1	*V* II 25.23(120), *Cr* II 24.85(20), (*Fe* I 25.46(80))
4226.89	2	*Ca* I 26.73(500), *Al* II 26.81(35), (*Fe* I 27.43(300))
4233.25	10	*Fe* II 33.17(11), (*Cr* II 33.25(10))
4238.98	0	*Fe* I 38.82(200), (*Cr* II 39.31(0))
4242.29	3	*Cr* II 42.38(30)
4244.77	0	*Ni* II 44.80(1), (*Cr* II 45.08(1))
4246.73	4	*Sc* II 46.83(500)

TABLE 2—*Continued*

Wave Length	Int.	Identification*
4250.46	0	*Fe* I 50.79(400), *Fe* I 50.13(250), (*Mo* II 50.69(125)), (*Cr* II 50.51(1))
4252.67	1	*Cr* II 52.62(10), (*Mn* II 53.02(2))
4254.07	0	*Cr* I 54.35(5000)
4257.99	1	*Fe* II 58.15(3), (*Zr* II 58.05(12))
4260.32	1	*Fe* I 60.48(400)
4261.85	2	*Cr* II 61.92(20)
4268.57	0	(*Fe* I 67.83(125)), (*Cr* II 69.28(10))
4271.34	1	*Fe* I 71.76(1000), *Fe* I 71.16(400)
4273.14	1	*Fe* II 73.32(3)
4274.35	0	*Cr* I 74.80(4000)
4275.63	2	*Cr* II 75.57(30), (*La* II 75.66(100))
4277.92	1	*Fe* II 78.13(1), (*Cr* II 78.10(1))
4282.74	0	*Fe* I 82.41(600), *Mn* II 82.50(3), (*Ca* I 83.01(40)), (*Cr* II 83.02(1))
4284.28	1	*Cr* II 84.21(20)
4287.79	1	*Ti* II 87.88(30)
4290.12	4	*Ti* II 90.23(60), (*Cr* I 89.72(3000))
4294.07	4	*Ti* II 94.12(80), *Fe* I 94.13(700)
4296.57	3	*Fe* II 96.57(6)
4298.78	0	*Fe* I 99.24(500), *Fe* I 98.04(100), *Ca* I 98.99(30)
4300.09	5	*Ti* II 00.05(100)
4301.99	4	*Ti* II 01.93(50)
4303.18	5	*Fe* II 03.17(8)
4305.94	1	*Fe* I 05.45(100), *Sc* II 05.71(20), *Sr* II 05.45(40)
4307.92	3	*Ti* II 07.91(100), *Fe* I 07.91(1000), (*Ca* I 07.74(45))
4309.04	0	*Fe* I 09.38(125), (*Cr* II 08.82(2))
4312.73	4	*Ti* II 12.87(100), (*Fe* II 13.03(1))
4314.55	6	*Fe* II 14.29(4), *Ti* II 14.98(100), *Fe* I 15.09(500), (*Sc* II 14.08(150))
4316.49	1	*Ti* II 16.80(35)
4319.32	0	(*Fe* II 19.72(1))
4320.86	3	*Ti* II 20.96(40), *Sc* II 20.75(40)
4325.40	5	*Fe* I 25.76(1000), (*Sc* II 25.01(40))
4330.40	3	*Ti* II 30.24(40), *Ti* II 30.71(30)
4332.58	1	.....
4337.86	4	*Ti* II 37.92(125)
4340.57	15	*H*γ 40.47(200)
4343.98	3n	*Ti* II 44.29(50), (*Cr* I 44.51(400)), (*Mn* II 43.99(2))
4348.20	0	*Al* II 47.78(20), (*Mn* II 48.49(1))
4351.72	8	*Fe* II 51.76(9), (*Mg* I 51.91(15))
4354.64	1	*Fe* II 54.36(2), (*Sc* II 54.61(10)), (*Ca* I 55.10(50)), (*La* II 54.44(200))
4357.63	1	*Fe* II 57.57(4)
4359.87	0	*Zr* II 59.74(10), (*Cr* I 59.63(200))
4367.86	3	*Ti* II 67.66(25), *Fe* II 68.26(1), *Fe* I 67.58(100), (*O* I 68.30(1000))
4369.50	1	*Fe* II 69.40(2), *Fe* I 69.77(200)
4374.58	3	*Sc* II 74.45(25), *Ti* II 74.82(35), *Y* II 74.95(300)
4377.48	1	*Mo* II 77.76(200)
4379.68	0	*Mn* II 79.74(1)
4384.73	6n	*Fe* II 85.38(7), *Fe* I 83.55(1000), *Mg* II 84.64(8), (*Fe* II 84.33(pred.))
4390.57	1n	*Ti* II 91.03(25), *Fe* I 90.95(100), *Mg* II 90.58(10), *Fe* II 89.40(1)
4395.06	5	*Ti* II 95.04(150)
4399.85	4	*Ti* II 99.77(100)
4404.57	1	*Fe* I 04.75(1000)
4406.72	1	(α Cygni)

TABLE 2—*Continued*

Wave Length	Int	Identification*
4409.32	0	*Ti* II 09.52(10), *Ti* II 09.22(8)
4411.36	2	*Ti* II 11.08(100)
4413.49	0	*Fe* II 13.60(0)
4415.20	2	*Fe* I 15.12(600), (*Sc* II 15.56(25))
4417.26	6	*Fe* II 16.82(7), *Ti* II 17.72(80)
4421.85	1n	*Ti* II 21.95(35)
4430.77	0n	*Fe* I 30.62(200), (*Fe* II 31.63(1))
4435.00	0n	*Ca* I 34.96(150), *Ca* I 35.69(100), *Fe* I 35.15(70)
4441.78	1	(*Fe* I 42.34(400)), (*Ti* II 41.72(pred.))
4443.95	5	*Ti* II 43.80(125)
4447.32	0	*Fe* I 47.72(200)
4450.34	3	*Ti* II 50.49(50)
4451.45	0	*Fe* II 51.54(4)
4455.34	1	*Fe* II 55.26(3), (*Ca* I 54.78(200))
4461.57	1	*Fe* I 61.65(300), (*Zr* II 61.22(10))
4464.39	1	*Ti* II 64.46(40)
4468.47	4	*Ti* II 68.50(150)
4470.57	1	*Ti* II 70.86(25)
4472.88	2	*Fe* II 72.92(2)
4478.47	0	(*Mn* II 78.74(1))
4481.43	2n	*Mg* II 81.33(100), *Fe* II 80.69(1)
4488.65	3	*Fe* II 89.18(4), *Ti* II 88.32(125)
4491.30	2	*Fe* II 91.40(5)
4495.26	1	(*Fe* II 95.52(pred.)), (*Ti* II 95.43(pred.))
4497.50	0	(*Zr* II 96.96(15)), (*Na* I 97.72(70))
4501.00	4	*Ti* II 01.28(100)
4508.16	5	*Fe* II 08.28(8)
4515.53	5	*Fe* II 15.34(7)
4520.20	4	*Fe* II 20.22(7)
4522.82	5	*Fe* II 22.63(9)
4524.68	0	*Ti* II 24.73(10), *Fe* I 25.15(100), *S* II 24.95(150)
4526.93	0	*Fe* II 26.58(m), *Ca* I 26.93(100)
4528.92	2	*Fe* I 28.62(600), *V* II 28.51(300)
4532.20	0	(*V* II 32.19(40))
4533.99	4	*Ti* II 33.97(150), *Fe* II 34.17(2), (*Mg* II 34.26(4))
4541.31	3n	*Fe* II 41.52(4)
4544.65	1	(*Ti* II 44.01(20)), (*Ti* II 45.14(15))
4549.57	7	*Fe* II 49.47(10), *Ti* II 49.63(200), *Fe* II 49.21(4)
4554.25	0	*Ba* II 54.04(1000), (*Zr* II 53.96(12))
4555.87	6	*Fe* II 55.89(8)
4558.69	4	*Cr* II 58.66(100), (*La* II 58.47(200))
4564.08	3n	*Ti* II 63.77(200), *V* II 64.59(200), (*Cr* II 64.27(1))
4566.88	1n	*Cr* II 65.78(10), *Ti* II 68.31(8)
4571.85	4	*Ti* II 71.98(300)
4576.72	3	*Fe* II 76.33(4)
4579.84	1	*Fe* II 80.05(1), *Fe* II 79.52(1), (*La* II 80.08(150))
4583.81	7	*Fe* II 83.83(11)
4588.36	3	*Cr* II 88.22(75), (*Al* II 48.19(30)
4591.91	1	*Cr* II 92.09(20)
4596.33	1	(*A* I 96.10(1000)), (*Fe* II 95.68(pred.))
4618.76	3nn	*Cr* II 18.83(35), *Cr* II 16.64(18), *Fe* II 20.51(3)
4629.39	5	*Fe* II 29.34(7), (*Ti* II 29.33(8))
4634.61	3n	*Fe* II 35.33(5), *Cr* II 34.11(25)
4649.35	0	(*Fe* II 48.93(0))
4657.05	2	*Fe* II 56.97(1), *Ti* II 57.21(18)
4666.43	1	*Fe* II 66.75(2)
4670.61	0	*Sc* II 70.40(300), (*Fe* II 70.17(0))
4675.51	1	.....

strong, relative to α Cygni, while *Fe* II and *Cr* II were strong and *Ti* II and *Mn* II were very weak. In 1941 all lines had become stronger, but *Ti* II and *Ca* II had become greatly strengthened, while *Fe* II and *Ni* II had not changed very greatly, so that by the end of 1941 the only marked difference between the metallic spectrum of Pleione and that of α Cygni (other than differences caused by dilution) was the weakness of *Mn* II in Pleione. In the last 14 months the lines of *Mn* II have also greatly increased in intensity, so that at the present time all these lines closely resemble those of α Cygni. The relevant ionization and excitation potentials of these elements are shown in the accompanying table.

Element	*Ni*	*Fe*	*Cr*	*Ti*	*Mn*
First ionization potential.....	7.6	7.8	6.7	6.8	7.4
Second ionization potential..	18.2	16.5	16.6	13.6	15.7
Exciting potential.....	3	3	3	1	2

The ionization potential of Mn^+ is intermediate between those of Ti^+ and Fe^+, and so are the relevant lower-excitation potentials. The exceptionally late strengthening of *Mn* II cannot be explained in terms of ordinary excitation or ionization. We are concerned here with a most puzzling question, the solution of which probably must be sought in the specific mechanism of line excitation which operates in each of these ions. The lower levels of all lines are metastable, and it is almost certain that the atoms in the shell reach these levels only by first absorbing some resonance line and then emitting a line of longer wave length, thus leaving the atom in the required metastable level. The populations in the metastable levels will, therefore, depend upon various factors, such as the transition probabilities for the resonance and excited lines, which are not sufficiently known at the present time.

4. The central intensities of the sharp *H* cores in Pleione are deeper than in α Cygni, in spite of the fact that the equivalent widths of the lines in α Cygni are greater than those of the cores in Pleione. This remarkable property is shared by nearly all shells. Figure 5 shows a tracing of *Hδ* on a recent plate of Pleione. The intensity of the line in the center corresponds to 14 per cent of the continuous spectrum. Correction for finite resolving-power should bring this value to about 10 per cent. This is in marked contrast to the central intensity of *Hδ* in α Cygni: 22 per cent, as determined by E. G. Williams,[3] or 35 per cent, as determined by S. Günther.[4] Roughly speaking, we can assume that the intensity of the line center in Pleione is one-half or one-third of that of α Cygni.

The interpretation of this phenomenon has an important bearing upon the theory of central line intensities. Following the procedure of Unsöld,[5] which he has recently justified in his discussion of the spectrum of τ Scorpii,[6] the central intensity of *Hδ* is attributed to thermal re-emission in the frequency of a line formed by pure absorption. In such a case the central intensity is independent of the oscillator strength of the line and is produced solely by the transfer mechanism of the radiation. The central intensity corresponds to the intensity of the continuous spectrum of the limb of the star—exactly as had first been shown in Schwarzschild's theory of stellar absorption lines.

The small central intensities in Pleione (and in other shells) must be due to the effect of dilution. The solid angle subtended by the disk of the star from a point in the shell is

$$W = \frac{R^2}{4r^2}.$$

[3] *Ann. Solar Phys. Obs., Cambridge*, **2**, Part II, 1932.

[4] *Zs. f. Ap.*, **7**, 106, 1933.

[5] *Physik der Sternatmosphären*, p. 301, Berlin, 1938.

[6] *Zs. f. Ap.*, **21**, 1941, available to us only in the form of advance proofs.

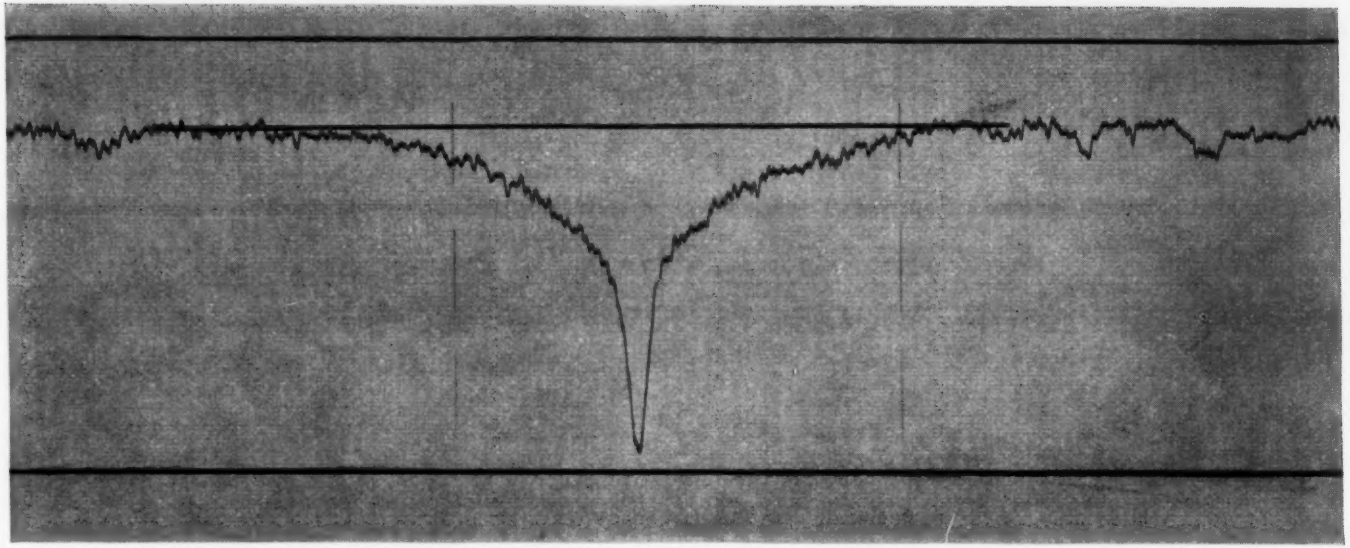


FIG. 5.—Tracing of $H\delta$ in Pleione (January 30, 1943). The three straight lines designate total darkness, continuous spectrum, and clear film. The distance between the continuous spectrum and the bottom of the line corresponds to a ratio of 1:0.14 in the intensities.

Hence the re-emission in the equation of transfer must be multiplied by the factor W. The problem is somewhat complicated, because we expect that in the shell Rosseland cycles will be operating, whose effect will be to increase the line-emission relative to the absorption. It is premature to try to estimate this effect. The best that we can do is to introduce a factor f such that, if n' is the ratio of the number of atoms in the upper state to the number in the lower state and n is the corresponding ratio in thermodynamic equilibrium at the temperature concerned, then

$$f = \frac{n'}{n} \geqslant 1 .$$

If we make use of Eddington's[7] designations, we can write the equation of transfer in the following form:

$$\cos\theta \frac{dJ'_\nu(\theta)}{\rho dr} = -(k+l)J'_\nu(\theta) + W(k+fl)J_T .$$

The solution follows closely Eddington's procedure. We introduce the optical depth

$$\tau = -\int k\rho dr$$

and reduce the equation to Eddington's formula (50). If $\eta = l/k$, we find that the central intensity of a line H'_ν/H is increased over the corresponding value in thermodynamic equilibrium by the factor

$$g = \frac{W(1+f\eta)}{1+\eta} .$$

The observed values are

$$g = 0.3 , \qquad W = 0.1 .$$

This would give an equation for f. But it should be remembered that with a constant value of k it is impossible to find lines produced by pure absorption which have smaller central intensities than 50 per cent, when $W = 1$ and $f = 1$. In order to account for the observed central intensities, Unsöld discusses the variation of k with wave length and determines for τ Scorpii the ratio $\bar{k}/k$. Hence it is meaningless to pursue this matter further, beyond concluding that the small central intensity in Pleione is caused by the factor W and that probably the full effect of this factor is checked by the opposite trend of the factor f. It seems plausible that this factor should be considerably smaller than $1/W$.

The duplicity and appreciable over-all width of the bright H lines shows that the shell is rotating with a fairly large velocity ($\sim$100 km/sec). Hence the emission from those parts of the shell which are not seen projected upon the apparent disk of the star are not superposed over the central intensities of the sharp absorption lines. Hence our treatment, neglecting this emission, was correct.

5. An inspection of Plates I and II shows that the metallic lines of Pleione are less weakened by continuous Balmer absorption than in α Cygni. This is a conspicuous phenomenon, apparently shared by some other shells (14 Comae). It is especially pronounced in the immediate vicinity of the Balmer limit, where the lines of Pleione on recent plates have much greater intensities than in α Cygni. The entire group of lines between *Ti* II 3641 and *Ti* II 3659 is much stronger in Pleione. To the red of the Balmer limit, λ 3647, this is probably in part due to the extreme sharpness of the lines of Pleione. Only when, for example, in the case of H 30 the wave length, λ 3612.26, agrees closely

[7] *M.N.*, **89**, 620, 1929.

with *Ti* II 3662.24, the metallic line is effectively suppressed. Perhaps the effect of the wings in α Cygni is more pronounced than had been considered probable in the past, and it is just possible that it may extend several angstrom units to the violet of λ 3647. This suggests an explanation of the strange phenomenon found by Struve and Sherman,[8] and emphasized by Greenstein,[9] that the weakening of metallic lines on the violet side of λ 3647 is more strongly correlated with distance to the limit than is compatible with the ν^3 factor in the continuous absorption coefficient.

The general absence of weakening of the metallic lines by the Balmer continuum of Pleione may be attributed to the semitransparency of the shell. The observed weakening in α Cygni and other A-type stars is due to the great optical depth of the reversing layer. The shell of Pleione can have only a relatively small optical depth, because photometric observations by Mündler[10] have shown only a small increase in brightness from 1939 to 1942, corresponding to less than 0.2 mag.

[8] *Ap. J.*, **91**, 428, 1940.

[9] *Pub. A.A.S.*, **10**, 295, 1942.

[10] *Beob. Zirk. d. A.N.*, **24**, No. 12, 1942.

VISUAL LIGHT-CURVE OF NOVA PUPPIS*

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Received February 22, 1943

Nova Puppis was discovered independently by the writer on the morning of November 12, 1942, after completion of a night's observing. The magnitude was estimated to be 0^m4 at the time, and the position and four low-dispersion spectra were obtained with

TABLE 1

OBSERVATIONS OF NOVA PUPPIS

Julian Day	Mag.	Julian Day	Mag.	Julian Day	Mag.	Julian Day	Mag.
676	0.4	694	5.7	713	6.4	732	6.8
677	0.8	695	5.75	715	6.65	735	6.8
678	1.15	696	5.8	716	6.8	737	6.75
679	1.95	697	5.75	717	6.8	738	6.8
680	2.4	701	6.15	718	6.7	739	6.85
681	3.1	702	6.1	719	6.7	740	6.8
682	3.4	704	6.1	720	6.6	741	6.75
683	3.8	705	6.4	722	6.6	743	6.75
685	4.2	707	6.3	723	6.6	744	6.8
686	4.2	708	6.25	724	6.7	745	6.85
687	4.3	709	6.5	725	6.7	746	6.9
689	4.8	710	6.6	726	6.75	747	7.0
690	4.95	711	6.6	727	6.75	751	6.95
691	5.2	712	6.55	728	6.8		

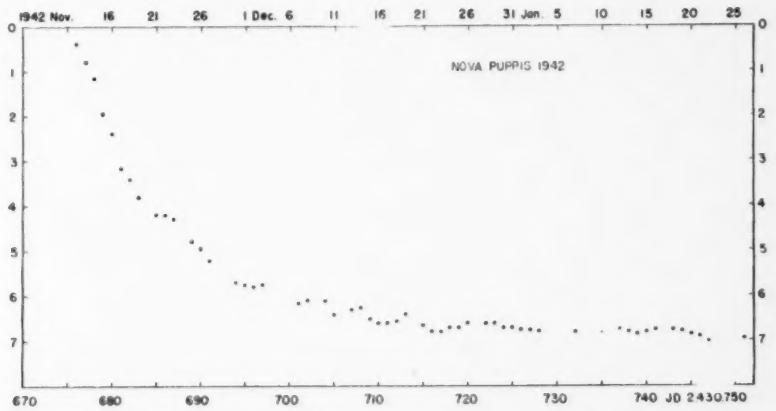

FIG. 1.—Visual light-curve of Nova Puppis

the 82-inch telescope just before sunrise. The spectra show a nova spectrum principally in absorption with a violet shift exceeding 1000 km/sec. A telegram announcing these results crossed with the telegram containing the discovery by Dawson.

* *Contributions from the McDonald Observatory, University of Texas*, No. 71.

Until the writer's departure from Texas on January 26, 1943, the visual magnitude of the nova has been determined on nearly every clear night. The color of the star was white at first but soon became yellow and later reddish. The comparison stars, selected from the *Henry Draper Catalogue*, were taken to match these colors as closely as possible. When the star fell below the third magnitude, the observations were made with a pair of binoculars.

The results obtained are given in Table 1 and are also shown in Figure 1. The observations during the first month (the steep part of the light-curve) were made at about the mean noon of Greenwich; the remaining observations were made somewhat earlier. Accordingly, the use of the fraction 0.0 is good enough for all Julian dates of this series; they might be added to the dates in Table 1.

It might be added that all the observations were made by directly looking at the objects to be compared; by averted vision the nova often appeared somewhat brighter than the magnitudes here given.

RECENT PROGRESS IN ASTROPHYSICS

THE SPECTROPHOTOMETRIC RESEARCHES OF BARBIER AND CHALONGE

In June, 1940, a photostat copy of the corrected proof of an article by Barbier and Chalonge[1] was received at the Yerkes Observatory. The paper, entitled "Etude du rayonnement continu de quelques étoiles entre 3100 et 4600 A," serves as a résumé of the work of these observers and of their collaborators, Vassy, Arnulf, Safir, Schahmanèche, Canavaggia, and Morguleff, who since 1933 have been engaged in a major investigation of the ultraviolet energy distribution of the stars. Because of the interruption of scientific communication, it seems profitable to present a sketch of these authors' conclusions, to reprint some of their more important tables, and to note a few critical points. I shall take responsibility for the accuracy of reproduction of their tabular data; the photostat copy indicates that the proof had been corrected.

The energy distributions were measured in 204 stars, mainly of early types. The observing station was on the Jungfrau, at an altitude of 3675 meters. The stellar spectra have a mean dispersion of 50 A/mm and were compared photographically with secondary standards which were tubes giving continuous spectra of molecular hydrogen. The latter were frequently compared with standard filament lamps, which were in turn compared with the lamps at the observatory at Göttingen; these again have been calibrated by the Physikalisch-technische Reichanstalt. Eight separate observing series were made, and the zero points of these series differ considerably. The primary standards proved to be quite stable, and the major source of zero-point errors was found in the calibration of the intensely blue hydrogen tubes by reddish filament lamps. The hydrogen tubes give spectra very similar to those of early-type stars, so that the photographic calibration curves introduce relatively small errors in the gradients of the stars with respect to the tubes. The largest series,[2] that of February to March, 1937, was adopted as standard, and zero points of each of the other series have been determined with respect to this series by means of stars common to both. All zero points were given equal weight in the determination of the final mean zero-point correction to all published observations. The various zero-point differences, or corrections to the published gradients, $\delta\varphi$, are given in Table 1. (The gradient for $\lambda > 3700$ A is φ_1; for $\lambda < 3700$ A, φ_2.) The actual corrected mean gradients of normal Henry Draper A0 stars then become $\varphi_1 = +1.00$ ($T_1 = 16{,}500°$) and $\varphi_2 = +1.39$ ($T_2 = 10{,}500°$). The total uncertainty of the zero point is considered to be still of the order of ± 0.10. An observation of unit weight has a probable error in φ of ± 0.08 if the spectral type is earlier than G0; the discontinuity in the logarithm of the intensity at the Balmer limit, D, has a probable error of ± 0.02.

A comparison of φ_1 with the measured gradients of other observers can be made; unfortunately no basis exists for comparison of the ultraviolet gradients φ_2. The possible variation of φ with wave length in the violet and near ultraviolet has not yet been independently determined. In comparing φ_1, with mean wave length λ 4250, with the gradients of other observers mainly to the red of this point, Barbier and Chalonge assume that the stars radiate like black bodies and transform the other gradients to λ 4250. There are 24 stars observed at Göttingen,[3] at mean wave length λ 5000. The mean dif-

[1] *Ann. d'ap.*, **4**, 1, 1941.

[2] Arnulf, Barbier, Chalonge, and Safir, *Ann. d'ap.*, **1**, 293, 1938.

[3] Kienle, Strassl, and Wempe, *Veröff-Univ. Sternwarte Göttingen*, No. 50, 1938.

ference between φ_1 and the corrected Göttingen gradients is +0.06; the scale difference does not exceed 1 per cent. The Greenwich observations[4] of 52 stars also give +0.06. Measures of 7 stars by R. C. Williams[5] give −0.15. In Table 2, I give a transcript of the corrected results of the spectrophotometric measurements and reduction of Barbier and Chalonge. The spectral types given are of various origin, mainly *Henry Draper Catalogue;* then follow: the visual magnitude; the discontinuity, D, in logarithm of intensity at the Balmer limit; p, the weight of the observations; φ_1, the gradient for $\lambda > 3700$; φ_2, the gradient for $\lambda < 3700$; $\Delta\varphi$, the difference of the gradients at λ 3700, derived from $\varphi_2' - \varphi_1'$, by correction of φ_2 and φ_1 to this wave length; λ_1, the apparent wave length of the point which lies halfway in logarithm of intensity between the intensity before and that beyond the Balmer limit; λ_0, the apparent wave length at which the full effect of the Balmer continuous absorption has been felt.

Studies of several variable stars have been made. The final reduction of the measures of β Persei shows that D is smaller by −0.02, φ_1 and φ_2 larger by about +0.1, at mid-eclipse than outside eclipse. No significant change of λ_1 is found. The Cepheid, α Ursae Minoris showed small variation of D and a variation of 0.1 in φ_1. The star γ Cassiopeiae

TABLE 1

CORRECTIONS TO THE PUBLISHED GRADIENTS

Series	$\delta\varphi_1$	$\delta\varphi_2$	Series	$\delta\varphi_1$	$\delta\varphi_2$
B. Sept.–Oct., 1935	−0.27	+0.10	F. Sept.–Oct., 1938	−0.02	+0.03
C. Feb.–Mar., 1937	− .10	− .12	G. Dec., 1938	+ .11	+ .13
D. Sept., 1937	− .10	+ .03	H. Mar., 1939	−0.02	−0.13
E. Feb.–Apr., 1938	+0.03	+0.03			

was studied in detail, and the variation of gradient measured during the period 1935–1939. The amplitude of the increase of gradient in the ultraviolet in 1937 was smaller than that reported by the Greenwich observers at mean wave length λ 5000. The gradient was observed to decrease with frequency but to become larger again beyond the Balmer limit. Table 3 gives the observed mean results of these measures.

The mean values of φ, D, etc., in normal stars are next discussed. The supergiants, emission-line objects, composite and abnormally reddened objects were excluded. I believe that some improvement in the discussion might result from the use of a more refined absolute magnitude and spectra classification and from the omission of all reddened B stars in the determination of the intrinsic color temperatures of these objects. Table 4 contains the statistical data as given by Barbier and Chalonge. The number of objects is n; the quantities E_D etc., are the mean deviations of individual stars from the mean, and T_1 and T_2 are the color temperatures in the given spectral region. The values of D, φ_2, and $\Delta\varphi$ are considered to be of low weight for stars later than F5.

Barbier and Chalonge remark that the quantity $\Delta\varphi$ has considerable theoretical importance. In A stars the continuous absorption beyond the Balmer limit is large enough so that φ_2 represents the emission at the boundary of the star, i.e., T_2 is close to the boundary temperature, T_0. Observationally, $\Delta\varphi$, although not very accurately determined, is correlated with D; for example, supergiants of types B and A have abnormally small

[4] *M.N.*, **94**, 488, 1934.

[5] *Pub. Obs. Michigan*, **7**, 147, 1939.

TABLE 2

CATALOGUE OF SPECTROPHOTOMETRIC RESULTS
(Barbier and Chalonge)

Star	Type	m_v	D	p	φ_1	p	φ_2	p	$\Delta\varphi$	λ_1	λ_0
α And	A0p	2.15	0.26	10	0.90	9.5	1.06	10	0.24	3752	3700
ο And	B5	3.63	.26	2	0.78	2	1.00	2	.32	.....	.....
φ And	B8	4.28	.31	3	0.85	3	0.84	2.5	.08	3735	3695
ζ Aqr	dF2	3.75	.21	1	1.88	1	1.46	1	− .40	3740	3680
π Aqr	B1e	4.64	.02	2	0.87	2	0.87	2	.09	.....	.....
α Aql	A5	0.89	.38	11	1.45	11	1.72	9	.31	3765	3705
δ Aql	F0	3.44	.27	2	1.60	2	1.70	2	.13	3764	3695
ζ Aql	A0	3.02	.48	5	0.87	4.5	1.17	3.5	.38	3764	3700
λ Aql	B9	3.55	.35	3	0.86	4	0.96	1.5	.19	3752	3700
β Ari	A5	2.72	.40	4	1.35	3.5	1.41	3.5	.12	3765	3705
35 Ari	B3	4.58	.20	2	0.56	2	0.94	2	.49	3746*	3700
41 Ari	B8	3.68	.34	2	0.70	2	1.08	2	.47	3750	3700
α Aur	gG0	0.21	.04	8	3.07	11	2.82	5.5	− .25	.....	.....
β Aur	A0p	var	.47	9	1.02	9	1.55	8.5	.59	3762	3700
ε Aur	cF5	3.30	.40	2	1.90	2	2.42	1.5	.53	3694	3650
η Aur	B3	3.28	.19	3	0.81	3	0.84	3	.11	3756	3705
θ Aur	A0p	2.71	.42	4	0.88	4	1.35	3.5	.55	3740	3685
χ^1 Aur	cB1	4.88	.08	2	1.30	2	1.28	1	.04	3716	3685
19 Aur	cA5	5.16	.41	1	1.50	1	1.18	0.5	− .27	3720	3680
α Boo	gK0	0.24	.....	.....	4.18	6	3.60	2	− .58	.....	.....
γ Boo	F0	3.00	.41	2	1.54	2	1.64	2	.13	3776*	3695
ζ Boo	A2	3.86	.46	1	1.11	1	1.34	1	.30	3772	3700
η Boo	dG0	2.80	.07	1.5	2.51	2	2.06	1	− .44	.....	.....
θ Boo	dF8	4.06	.14	2	2.16	2	1.83	2	− .31	3749*	3685*
α Cam	B0e	4.38	.03	7	0.93	7	0.87	7	.03	.....	.....
1H Cam	B3e	4.76	.09	2	0.84	2	0.87	1.5	.12	.....	.....
2H Cam	cB9	4.42	.17	3	1.53	3	1.50	2.5	.01	3701	3670
γ Cap	F0p	3.80	.26	2	1.82	2	1.88	1	.09	3763	3690
δ Cap	A5	2.98	.29	1	1.26	1	1.47	0.5	.26	3757	3710
β Cas	dF5	2.42	.29	2	1.74	3	1.79	0.5	.08	3754	3670
γ Cas	B0e	var	.....	.....	.....	.....	.....	.....	.....	.....	.....
δ Cas	A5	var	.46	6	1.17	7	1.45	5	.33	3762	3705
ε Cas	B3	3.44	.21	2	0.97	2	1.01	1.5	.12	3736	3685
ζ Cas	B3	3.72	.12	2	0.76	2	0.78	2	.12	3740	3705
κ Cas	cB0e	4.24	.04	5	1.12	5	1.11	5	.16	.....	.....
α Cep	A5	2.60	.36	7	1.54	6.5	1.60	2.5	.09	3762	3705
β Cep	B1	3.32	.08	5	0.63	5	0.73	5	.11	3751	3710
κ Cep	B9	4.40	.40	2	0.92	2	1.31	1.5	.47	3752	3705
λ Cep	Od	5.19	.01	1	1.36	1	0.83	0.5	− .47	.....	.....
ν Cep	cA2	4.46	.28	1	1.74	1	1.48	1	− .23	3697	3665
6 Cep	B3e	5.18	.11	2	1.10	2	1.02	1.5	.00	.....	.....
9 Cep	cB2	4.87	.07	3	1.48	3	1.38	1.5	− .05	3720	3690
δ Cet	B2	4.04	.09	2	0.70	2	0.84	1.5	.24	3747*	3710
μ Cet	F0	4.36	.28	1	1.61	1	1.69	1	.11	3760	3700
α CMa	A0	−1.6	.47	15	1.00	15	1.48	16.5	.54	3774	3695
β CMa	cB1	1.99	.08	9	0.71	9	0.70	7.5	.09	3743	3695
δ CMa	cF8	1.98	.20	2	2.58	3	2.40	0.5	− .18	3729	3690*
ε CMa	cB1	1.63	.07	4	0.73	5	0.88	3	.25	3746	3700
η CMa	cB5	2.43	.11	3	0.95	3	0.88	1.5	.02	3712	3680
o^2 CMa	cB5	3.12	.08	2	0.84	2	0.94	1	.19	3716	3680
α CMi	dF5	0.48	.18	12	2.00	12	1.97	12.5	− .01	3746	3680
β CMi	B8e	3.09	.35	2	0.88	2	1.02	2	.23	3747	3695
α Cnc	A3	4.27	.39	1	1.49	1	1.51	1	.06	3766	3705
α CrB	A0	2.31	.45	9	1.07	7.5	1.41	6.5	.41	3762	3705
β CrB	F0p	3.72	0.28	2	1.67	2.5	1.66	1	0.02	3778	3700

* Value uncertain.

TABLE 2—*Continued*

Star	Type	m_v	D	p	φ_1	p	φ_2	p	$\Delta\varphi$	λ_1	λ_0
θ CrB	B5e	4.17	0.24	4	0.84	4	0.92	4	0.17	.....	.....
α Crv	dF2	4.18	.20	2	1.54	3	.....	.....	.....	3782*	3690
γ Crv	B8	2.78	.30	2	0.92	2	1.28	2	0.44	3743	3705
δ Crv	A0	3.11	.41	2	1.04	2	1.18	2	0.21	3764	3705
θ Crt	B9	4.81	.38	2	1.01	2	0.95	1	0.02	3752	3710
α^2 CVn	A0p	2.90	.29	5	1.04	5	1.16	5	0.19	3752	3700
α Cyg	cA2e	1.33	.33	15	1.24	14	1.78	12.5	0.59	3697	3665
γ Cyg	cF8	2.32	.24	4	2.66	4	2.07	2.5	−0.58	3700	3680
δ Cyg	A0	2.97	.42	3	1.02	2.5	1.48	1.5	0.52	3745	3700
λ Cyg	B5e	4.47	.22	2	0.96	2	0.86	2	−0.01	.....	.....
σ Cyg	cA0	4.28	.21	3	1.10	3	1.08	3	0.05	3706	3665
τ Cyg	F0	3.82	.18	1	1.94	1	1.84	1	−0.08	3730	3680
υ Cyg	B3e	4.42	.08	2	1.08	2	0.93	1.5	−0.07	.....	.....
P Cyg	B1e	5.00	.00	4	1.62	4	1.17	1.5	−0.41	.....	.....
f^1 Cyg	B0e	4.86	− .01	2	0.88	2	0.70	2	−0.09	.....	.....
55 Cyg	cB2e	4.89	.04	2	1.53	2	1.39	1.5	−0.09	.....	.....
68 Cyg	Oe5	5.06	.02	2	1.03	2	0.66	2	−0.28	3725*	3700
α Del	B8	3.88	.41	2	0.78	2	1.16	2	0.47	3751	3690
ϵ Del	B5	3.98	.28	2	0.70	2	1.04	2	0.44	3746	3700
α Dra	A0p	3.64	.46	2	0.93	3	1.23	2	0.28	3750	3690
β Dra	cG0	2.99	.04	3	3.34	3	.....	.....	.....	.....	.....
ζ Dra	B5	3.22	.27	2	1.00	3	0.90	2	−0.02	3737	3690
η Dra	gG5	2.89	.....	.....	3.20	2.5	.....	.....	.....	.....	.....
κ Dra	B5e	3.88	.28	7	0.94	7	0.92	6.5	0.07	.....	.....
β Eri	A3	2.92	.43	3.5	1.32	5	1.57	1.5	0.30	3762	3690
o^1 Eri	dF2	4.14	.26	2	1.79	2	1.58	2	−0.18	3747	3685
α Gem	A0	1.59	.45	18	1.07	17.5	1.40	15.5	0.40	3765	3695
β Gem	gK0	1.21	.....	.....	3.77	3	3.39	1.5	−0.38	.....	.....
γ Gem	A0	1.93	.51	16	1.01	16	1.46	11	0.51	3752	3695
δ Gem	F0	3.51	.22	2	1.78	2	1.69	1.5	−0.06	3760	3700
ζ Gem	CG0	var†	.05	5	3.24	5	1.96	2	−1.27	.....	.....
θ Gem	A2	3.64	.45	3	1.34	3	1.28	2.5	0.00	3752	3699
λ Gem	A2	3.65	.40	2	1.28	2	1.41	1.5	0.19	3764	3705
ν Gem	B5e	4.06	.24	2	0.95	2	0.99	1.5	0.13	.....	.....
γ Her	F0	3.79	.37	2	1.56	2	1.73	1.5	0.20	3758	3680
δ Her	A2	3.16	.43	2	1.20	2	1.63	1.5	0.48	3768	3695
ζ Her	dG0	3.00	.06	2	2.60	3	2.67	1.5	0.07	.....	.....
ι Her	B3	3.79	.17	6	0.86	6	0.78	5.5	0.01	3758	3700
τ Her	B5	3.91	.22	2	1.01	2	0.78	2	−0.15	3747	3690
φ Her	B9p	4.26	.30	2	0.99	2	1.21	1	0.29	3758	3700
u Her	B3	4.8	.14	2	0.80	2	0.75	1	0.04	3756	3705
ϵ Hyd	dF8	3.48	.12	2	2.46	2	2.28	2	−0.17	3790*	3700
10 Lac	Oe5	4.91	.04	2	0.62	2	0.52	2	0.02	3758	3710
α Leo	B8	1.34	.34	15	0.82	15	1.12	14.5	0.38	3740	3695
β Leo	A2	2.23	.47	12.5	1.14	14.5	1.56	8	0.47	3774	3700
δ Leo	A3	2.58	.45	10	1.26	10	1.59	7	0.38	3770	3700
ζ Leo	F0	3.65	.30	2	1.82	2	1.78	1	−0.01	3746	3690
η Leo	cA0	3.58	.36	4	1.03	4	1.39	4	0.43	3713	3680
θ Leo	A0	3.41	.48	5	1.08	5	1.48	4	0.46	3760	3690
ρ Leo	cB0	3.85	.05	3	0.88	3	0.80	3	0.01	3718	3700
α Lep	cF0	2.69	.55	3	1.32	3	1.63	1.5	0.36	3720	3655
β Lep	gG0	2.96	.01	2.5	3.09	3	.....	.....	.....	.....	.....
α^2 Lib	A3	2.90	.42	2	1.31	4	1.41	1	0.16	3772	3700
β Lib	B8	2.74	.33	5	0.86	5	1.08	3.5	0.30	3738	3675
38 Lyn	A2	3.82	.43	1	1.15	1	1.27	1	0.18	3769	3705
α Lyr	A0	0.14	.49	17	1.14	17	1.43	18	0.34	3771	3695
β Lyr	cB8	var†	.49	17	1.04	17	1.25	16.5	0.28	.....	.....
γ Lyr	A0p	3.30	.46	3	0.98	3	1.40	2	0.49	3725	3680
β Mon	B2e	3.93	0.16	2	0.84	2	0.88	2	0.13	.....	.....

† Mean value over cycle of variation.

TABLE 2—*Continued*

Star	Type	m_v	D	p	φ_1	p	φ_2	p	$\Delta\varphi$	λ_1	λ_0
S Mon	Oe5	4.68	0.01	2	0.58	2	0.58	2	0.12	3747	3705
13 Mon	cA0	4.50	.33	3	1.14	3	1.25	2	.17	3714	3670
α Oph	A5	2.14	.41	10	1.34	9.5	1.70	6	.41	3762	3695
ζ Oph	B0	2.70	.02	5	0.90	4.5	0.90	4	.09	3742	3710
η Oph	A2	2.63	.42	3.5	1.16	4	1.07	2	− .03	3768	3700
κ Oph	gK0	var	.....	.....	3.75	1	.....	.....	.....	.....	.....
χ Oph	B3e	4.85	− .02	3	1.29	3	1.16	1	− .07	.....	.....
66 Oph	B3e	4.81	.10	2	1.04	2	0.84	1.5	− .12	.....	.....
67 Oph	cB5	3.92	.14	2.5	1.04	3	1.15	1	.18	3723	3690
α Ori	cMa	var	.....	.....	6.03	5	.....	.....	.....	.....	.....
β Ori	cB8	0.34	.16	17	0.99	16	1.19	15	.27	3710	3670
γ Ori	B2	1.70	.12	17	0.69	16.5	0.80	16.5	.21	3740	3700
δ Ori	B0	2.48	.03	14	0.67	13.5	0.74	13.5	.17	3740	3705
ε Ori	B0	1.75	.03	43	0.72	42	0.78	28	.16	3727	3700
ζ Ori	B0	2.05	.02	12	0.73	12	0.72	12	.07	3728	3705
η Ori	B1	3.44	.08	2	0.71	2	0.78	2	.17	3760	3700
κ Ori	cB0	2.20	.04	14	0.75	14	0.76	13.5	.11	3728	3700
λ Ori	Oe5	3.66	.03	3	0.52	2	0.76	3	.35	3738	3705
π^3 Ori	dF8	3.31	.12	2	2.02	2	1.86	1.5	− .14	3760	3670
π^4 Ori	B3	3.78	.12	4	0.80	4	0.84	4	.13	3734	3700
π^5 Ori	B3	3.87	.12	4	0.76	4	0.74	3.5	.08	3735	3700
σ Ori	B0	3.78	.06	2	0.73	2	0.62	2	− .08	3756	3705
τ Ori	B5	3.68	.25	3	0.94	3	1.19	1.5	.33	3744	3700
χ^2 Ori	cB2	4.71	.04	2	1.24	2	1.08	2	− .10	3706*	3690
ω Ori	B3e	4.54	.10	3	1.10	3	0.87	3	− .15	.....	.....
25 Ori	B3e	4.73	.02	2	1.06	2	1.00	2	.02	.....	.....
α Peg	A0	2.57	.48	8	0.92	8	1.38	7	.54	3748	3690
β Peg	gMa	2.61	.....	.....	5.76	2	.....	.....	.....	.....	.....
γ Peg	B2	2.87	.12	9	0.72	9	0.74	9	.12	3746	3700
ζ Peg	B8	3.61	.38	2	0.97	2	1.06	2	.16	3738	3695
κ Peg	dF5	4.27	.16	1	1.91	1	1.68	1	− .21	3751	3690
π Peg	gF5	4.38	.24	1	2.01	1	1.84	1	− .15	3751	3690
ξ Peg	dF5	4.31	.09	2	2.11	2	1.65	1.5	− .44	.....	3700
31 Peg	B3e	4.93	.12	1	0.68	1	.....	.....	.....	.....	.....
α Per	cF5	1.90	.36	4	2.12	5	2.29	3	.17	3712	3675
β Per	B8	var‡	.32	15	0.96	15	1.15	14.5	.27	3752	3700
γ Per	Comp.	3.08	.26	2	2.50	2	1.82	0.5	− .67	.....	.....
δ Per	B5	3.10	.25	5	0.86	5	0.92	5	− .15	3734	3695
ε Per	B1	2.96	.06	6	0.75	6	0.74	6	.09	3734	3695
ζ Per	cB1	2.91	.05	7	1.18	6.5	1.11	6.5	− .01	3730	3695
θ Per	dF8	4.22	.08	2	2.28	2	1.76	2	− .50	3716	3690
ν Per	cF5	3.93	.28	2	1.96	2	2.00	2	.06	3720	3665
o Per	B1	3.94	.06	2	1.12	2	1.11	1.5	.06	3738	3700
ξ Per	Oe5	4.05	.03	2	1.19	2	0.80	2	− .32	3714	3705
φ Per	B0e	4.19	.02	6	0.99	6	0.88	5	− .03	.....	.....
ψ Per	B5e	4.26	.14	2	1.08	2	1.06	2	.05	.....	.....
c Per	B3e	4.03	.16	2	1.18	2	0.94	1.5	− .17	.....	.....
16 Per	F0	4.27	.25	2	1.79	2	1.77	2	.01	3754	3695
β Psc	B5e	4.58	.19	2	1.00	2	1.07	1.5	.14	.....	.....
α PsA	A3	1.29	.45	2.5	1.17	4	1.15	0.5	.04	3770	3700
ρ Pup	cF5	2.88	.21	2	2.16	2	2.17	0.5	.02	3732	3690
α Sco	cMa	1.22	.....	.....	5.36	2	.....	.....	.....	.....	.....
β Sco	B1	2.90	.07	2	0.88	2	0.79	1.5	.00	3760	3705
δ Sco	B0	2.54	.07	5	0.77	5	0.99	4.5	.32	3754	3705
π Sco	B2	3.00	.06	2	0.74	2	0.70	1.5	.07	3764*	3705
τ Sco	B0	2.91	.05	2	0.68	2	0.71	1.5	.13	3744	3700
β Ser	A2	3.74	.43	1	1.27	1	1.56	1	.34	3762	3700
ε Ser	A2	3.75	0.42	1	1.34	1	1.43	1	0.14	3794	3700

‡ Mean value outside of eclipse.

TABLE 2—*Continued*

Star	Type	m_v	D	p	φ_1	p	φ_2	p	$\Delta\varphi$	λ_1	λ_0
π Sgr	cF2	3.02	0.38	2	1.56	2	2.30	0.5	0.76	3740	3670
υ Sgr	Comp.	4.58	.00	1	1.11	1	1.34	1	0.30	.....	.....
α Tau	gK5	1.06	.....	.....	5.40	4.5	3.73	0.5	−1.67	.....	.....
β Tau	B8	1.78	.27	7	0.83	6.5	1.09	7	0.34	3739	3695
ζ Tau	B3e	3.00	.18	6	0.68	6	0.75	6	0.17	.....	.....
η Tau	B5e	2.96	.31	5	1.00	5	1.22	4	0.29	.....	.....
λ Tau	B3	3.3	.21	2	0.82	2	1.02	2	0.29	3743	3700
ξ Tau	B8	3.75	.30	2	0.92	2	0.96	2	0.13	3760	3710
20 Tau	B5	4.02	.24	2	1.06	2	1.26	2	0.27	3733	3700
23 Tau	B5e	4.25	.24	2	1.13	4	1.15	2	0.08	.....	.....
27 Tau	B8	3.80	.30	2	0.86	2	1.29	1.5	0.51	3738	3690
90 Tau	A3	4.30	.41	2	1.32	2	1.35	1.5	0.09	3766	3695
α Tri	dF5	3.58	.11	1	2.29	1	1.96	1	−0.31	3731	3680
β Tri	A5	3.08	.43	3	1.35	2.5	1.30	1.5	0.01	3759	3690
α UMa	gK0	1.95	.....	.....	3.73	5	2.78	2	−0.95	.....	.....
β UMa	A0	2.44	.48	9	0.98	11	1.45	8	0.53	3763	3690
γ UMa	A0	2.54	.50	7	1.02	8	1.40	6	0.45	3757	3695
δ UMa	A2	3.44	.42	2	1.22	1.5	1.64	2	0.47	3768	3700
ϵ UMa	A0p	1.68	.51	19	0.99	20	1.34	16	0.42	3751	3695
ζ UMa	A2p	2.40	.46	11	1.07	13	1.39	7.5	0.39	3769	3700
η UMa	B3	1.91	.19	39	0.79	39	0.88	29.5	0.18	3754	3705
ι UMa	A5	3.12	.39	3	1.43	3	1.62	2	0.20	3769	3695
λ UMa	A2	3.52	.46	3	1.00	3	1.46	3	0.52	3764	3700
υ UMa	F0	3.89	.30	2	1.62	2	1.68	2	0.09	3754*	3690
23 UMa	F0	3.75	.28	2	1.60	2	1.86	2	0.29	3762	3690
α UMi	cF8	var†	.26	27	2.40	29	2.30	12.5	−0.09	3707	3690
γ UMi	A2	3.14	.53	6	1.10	6	1.73	3.5	0.69	3730	3680
ζ UMi	A2	4.34	.46	2	1.16	2	1.47	2	0.36	3758	3690
α Vir	B2	1.21	.10	17	0.68	17	0.75	13.5	0.17	3748	3700
β Vir	dF8	3.80	.10	2	2.12	2	2.10	2	0.00	3764	3690
γ Vir	F0	2.90	.22	2	1.79	2	1.68	1.5	−0.08	3776	3690
ζ Vir	A2	3.44	0.40	2	1.26	2	1.37	2	0.17	3766	3710

values of D for their spectral type and correspondingly small $\Delta\varphi$; in F supergiants both D and $\Delta\varphi$ are larger than normal.[6]

A separate discussion of emission-line B stars shows that D is less than normal and may even become negative because of the continuous emission of hydrogen in the upper layers or shells of the stars. The quantity $\Delta\varphi$ is, in general, small; the interpretation of φ_2 and $\Delta\varphi$ is complicated by the superposition of the continuous spectrum of the photosphere and the recombination emission of the shell. In γ Cassiopeiae, however, $\Delta\varphi$ was very large and positive during the emission stages. The source of so striking a difference may well be found in the high opacity of the shell of γ Cassiopeiae compared to those of normal Be stars. The emission has relatively negligible effects in stars later than B5.

The effect of interstellar absorption on the shape of the stellar energy-curves is discussed for the stars ζ Persei, χ^2 Orionis, and 9 Cephei. Since their base line was so short, it was necessary to combine the measures of ultraviolet gradient with those made by other observers in other spectral regions. In general, I feel that such a method is subject to all the uncertainties of the absolute zero-point errors of the various spectrophoto-

[6] I have made an unpublished spectrophotometric study of the supergiants of types B1 to A2 near the clusters h and χ Persei which confirms the low value of D for these supergiants. An independent observational determination of φ_2, and therefore of $\Delta\varphi$, remains one of the important problems in spectrophotometry. As yet no completely satisfactory theoretical reason has been advanced for the small values of D and $\Delta\varphi$ in A supergiants; in F supergiants the dissociation of the negative hydrogen ions would result in the opacity being more nearly that of pure hydrogen than it is in dwarfs and, consequently would result in larger values of D. No complete theoretical computation of $\Delta\varphi$ as a function of temperature and pressure has yet been made.

metric scales; and some disturbing features are to be noted. Barbier and Chalonge find an apparent continuous increase of gradient with frequency in all stars. In ζ Persei, type cB1, with negligible values of D and $\Delta\varphi$, the gradient is 0.66 in the visual and 0.37 near λ 3700. In χ^2 Orionis the gradient decreases from 1.1 to 0.3. Recent exact measurements over a wider base line, such as those of Stebbins and Whitford,[7] show in all cases

TABLE 3

OBSERVATIONS OF γ CASSIOPEIAE

Mean Epoch	D	p	φ_1	p	φ_2	p	$\Delta\varphi$
1935.73	−0.13	7	0.96	7	1.18	4.5	+0.30
37.13	.22	6	1.02	6	1.48	6	.52
37.67	.29	3	1.16	3	1.50	3	.39
38.19	.21	7	0.85	7	1.51	7	.73
38.68	.15	7	0.85	7	1.28	7	.51
38.98	.12	2	0.78	1	1.09	2	.40
39.21	−0.05	2	0.60	2	1.05	1.5	+0.56

TABLE 4

STATISTICAL DATA FOR NORMAL STARS

Type	n	D	E_D	φ_1	E_{φ_1}	$T_1\times10^{-3}$	φ_2	E_{φ_2}	$T_2\times10^{-3}$	$\Delta\varphi$	$E_{\Delta\varphi}$
Oe5	3	0.03	0.01	0.57	0.04	52	0.62	0.09	29	+0.16	0.12
B0	7	.04	.02	0.74	.05	28	0.78	.09	20	+0.12	.08
B1	4	.07	.01	0.74	.07	28	0.78	.05	20	+0.09	.05
B2	6	.11	.02	0.73	.04	29	0.78	.06	20	+0.16	.05
B3	10	.17	.03	0.79	.06	25	0.86	.08	18	+0.16	.10
B5	6	.25	.02	0.93	.10	18	1.02	.15	15	+0.17	.18
B8	11	.33	.03	0.86	.06	21	1.10	.10	13.5	+0.32	.12
B9	4	.36	.03	0.94	.06	18	1.11	.15	13	+0.24	.14
A0	17	.47	.02	1.00	.05	16.5	1.39	.08	10.5	+0.45	.08
A2	15	.44	.02	1.19	.08	13	1.44	.13	10	+0.31	.16
A3	6	.42	.02	1.31	.06	11.5	1.43	.12	10	+0.17	.11
A5	8	.39	.04	1.36	.08	11	1.53	.15	9.5	+0.22	.11
F0	13	.28	.04	1.70	.11	8.6	1.74	.07	8.3	+0.06	.09
F2	3	.22	.02	1.74	.13	8.4	1.52	.06	9.5	−0.29	.11
gF5	1	.24	.....	2.01	.....	7.2	1.84	.....	7.8	−0.16	.....
dF5	5	.17	.06	2.01	.15	7.2	1.81	.12	8.0	−0.24	.17
dF8	5	.11	.02	2.21	.13	6.5	1.97	.18	7.3	−0.22	.14
gG0	2	.02	.02	3.08	.01	4.65	2.82	.....	5.05	−0.25	.....
dG0	2	0.06	0.01	2.56	.04	5.75	2.36	.30	6.1	−0.18	.26
gG5	1	.....	.....	3.20	.....	4.5	.....	.....	.....	.....	.....
gK0	4	.....	.....	3.86	.16	3.75	3.26	0.32	4.4	−0.64	0.20
gK5	1	.....	.....	5.40	.....	2.65	3.73	.....	3.8	−1.67	.....
gMa	3	.....	.....	5.72	0.24	2.5	.....	.....	.....	.....	.....

only a slight decrease (from λ 10,000 to λ 4000) of the relative gradient of a reddened with respect to an unreddened B star. The result of the discussion by Barbier and Chalonge is that there is required either a strong deviation from the λ^{-1} law of interstellar reddening or strong deviations from black-body radiation in the violet and near ultraviolet. Further investigation of the ultraviolet energy distribution of early-type stars seems desirable, since some of the above discrepancy may be ascribed to residual uncertainties in the absolute calibration in this region.

JESSE L. GREENSTEIN

December 24, 1942

[7] *Ap. J.*, **90**, 209, 1939; also extensive unpublished material.

NOTES

HD 15963, A NEW SHELL STAR

The star HD 15963, magnitude 7.96, is classified in the *Henry Draper Catalogue* as A0p, with the remark: "The lines are somewhat narrow, and numerous peculiar lines of well marked intensity are seen, resembling those in the spectrum of α Cygni. These lines may be due to the spectrum of a fainter component." The star was included in the c-star catalogue of Miss Payne[1] and as a result is listed in the c-star catalogues of Merrill[2] and Wilson.[3] The spectrum was apparently not obtained at Mount Wilson.

In the course of investigation of stars in the region of the double cluster in Perseus, this object was noted as peculiar because of the simultaneous presence of an α Cygni-like spectrum and abnormally broad *He* I lines, λ 4026 and λ 4009. The Balmer series appears very sharp and strong, but there is an indication of underlying wings to the hydrogen lines. Further investigation showed that the *Si* II and *Mg* II lines are much weaker than in the supergiant α Cygni, and also that other helium lines at λλ 4121, 4144, and 4471 are present, though much broadened. It was then suspected that this object is in reality a shell star and that the former classification as a c star was due to a false absolute-magnitude effect shown by the lines arising from the shell.

A plate taken by Dr. Struve with the Cassegrain quartz spectrograph attached to the 82-inch reflector of the McDonald Observatory confirms completely the low-dispersion observations. The Balmer series can be seen easily up to *H* 24, since the lines have very deep and sharp cores. The broad wings due to the underlying star are also visible and are approximately symmetrical with respect to the cores, showing that there is no appreciable expansion of the shell. The *He* I lines are very broad, the lines of *Mg* II and *Si* II very weak. Further, the spectrum shows strong and sharp lines of *Fe* II and also some sharp lines of *Ti* II, which are weaker in this shell than in most others. The lines of *Mg* I are present and sharp.

This star is notable in that it does not show emission, although it is in the field covered thoroughly by the Mount Wilson surveys.[4] Our spectra show that *Hβ* is strong in absorption but do not give any information on *Hα*. The class of the underlying star may be estimated as around B3. The star is probably more luminous than the main-sequence stars of its class but still 3 or 4 mag. fainter than the shell spectrum would lead us to expect, were it not for the weakness of *Si* II and *Mg* II and the presence of the broad *He* I lines. The spectrum has apparently not changed significantly since the Harvard observations.

W. P. Bidelman

Yerkes Observatory
March 11, 1943

[1] *The Stars of High Luminosity*, *Harvard Monograph* No. 3, 1930.

[2] *Ap. J.*, **81**, 352, 1935.

[3] *Ap. J.*, **93**, 212, 1941.

[4] *Ap. J.*, **76**, 156, 1932.

THE RADIAL VELOCITY OF 27 CANIS MAJORIS

New observations of this star during the present season bring out an interesting property which was not heretofore apparent. The depths of the three minima of the velocity-curve thus far observed show a definite progression: the velocity was about −100 km/sec in 1927, −50 km/sec in 1934, and −20 km/sec in 1942. There is a strong

TABLE 1

RADIAL VELOCITIES OF 27 CANIS MAJORIS

Date	U.T.	Velocity in Km/Sec	Date	U.T.	Velocity in Km/Sec
1942 Oct. 8	10:58	+34	1942 Nov. 27	10:13	+48
Oct. 18	10:54	33	Dec. 4	9:27	43
Oct. 27	10:54	46	Dec. 16	8:01	55
Nov. 6	10:38	51	1943 Feb. 16	4:27	22
Nov. 18	10:26	+38	Feb. 19	4:14	+22

suspicion that the two maxima were also unequal: +120 km/sec in 1931 and +90 km/sec in 1939. Hence it is apparent that the range of the velocity-curve has steadily decreased since observations were started at the Yerkes Observatory in 1925. The observations listed in Table 1, when plotted on the velocity-curve published last year,[1] show that the last minimum occurred about on JD 2430400. Accordingly the two observed intervals between minima were 2300 days and 2800 days. It is not possible to reconcile the difference between these intervals.

OTTO STRUVE

YERKES OBSERVATORY
February 5, 1943

[1] *Ap. J.*, **96**, 311, 1942.

REVIEWS

The Theory of the Photographic Process. By C. E. KENNETH MEES. New York: Macmillan Co., 1942. Pp. x+1124. $12.00.

Dr. Mees's purpose in writing this book is to bring under one cover a summary of the most important literature on the photographic process. He has been assisted by numerous members of his scientific staff at the Kodak Research Laboratories. The book is divided into six parts of from three to eight chapters each. The parts are: (I) "The Photographic Material," (II) "The Action of Light," (III) "Development and the After Processes," (IV) "Sensitometry," (V) "Photographic Physics," (VI) "Optical Sensitizing." Each chapter is provided with an extensive bibliography. Author and subject indexes complete the book. The chapter bibliographies constitute one of the most attractive features of the book. The twenty-page chapter on reciprocity and intermittency effects, for example, contains forty-four references to the literature. The references are not arranged chronologically or alphabetically by author.

With the exceptions of the emulsion-maker, most of whose methods are secret, and the developer of color processes, no worker in the field of photographic research can feel slighted by Dr. Mees's coverage. Subjects as far removed from the theory of the photographic process as sound-recording, gold-toning, and the construction of sensitometers are given careful consideration. After looking through this book one has the feeling that, while recent advances in physical and chemical knowledge have been instrumental in clearing up some of the important questions in photographic theory, there are still many experimental facts that are as yet poorly accounted for.

Those topics that have been under discussion for many years are given an essentially historical treatment. For example, Carey Lea's early work on the nature of the latent image, carried out before 1890, covers two pages of the book, and it is not until forty pages later that the successful Gurney-Mott theory is discussed. Similar treatment is given to such subjects as formulae for the characteristic curve of an emulsion and the comparative action of the various developing agents. Those fields which are less controversial, and in which most of the important work has been carried out in recent years in the Kodak Laboratories, are covered with less regard to history. Such chapters are those on the theory of tone reproduction, the sensitizing and desensitizing dyes, and the sizes of the silver halide grain.

This is one of the few books on photography written in English which are intended for the scientist rather than for the photographer.

DANIEL M. POPPER

Yerkes Observatory

Weather: An Introductory Meteorology. By W. G. KENDREN. New York and Toronto: Oxford University Press, 1943. Pp. 96. $1.00.

This little book contains a compact treatment of meteorology, written in nontechnical language. It is intended primarily for the student pilot, "for whom a knowledge of the composition of weather is a basic requirement." The successive chapters are: "The Atmosphere"; "Temperature"; "The Water Vapor in the Atmosphere"; "Barometric Pressure"; "Winds"; "Vertical Movements of the Atmosphere"; "Temperature Changes in Air Due to Ascent and Descent"; "Turbulence"; "Clouds"; "Visibility"; "Pressure Systems in the Westerlies"; "Air Masses"; "The Structure of Depressions, Fronts"; "The Movement of Depressions and Fronts"; "Anticyclones"; "The Synoptic Chart, Forecasting."

Original Tables to 137 Decimal Places of Natural Logarithms for Factors of the Form $1 \pm n.10^{-p}$, *Enhanced by Auxiliary Tables of Logarithms of Small Integers.* By HORACE S. UHLER. New Haven: Yale University Press, 1942. Pp. 120.

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